Department of
Computer Science

UNIVERSITY OF
BATH

Technical Report

Undergraduate Dissertation: A Simulated Exploration into the Growth of Modern Terrorist Networks

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Technical Report 2006-18 December 2006

ISSN 1740-9497

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ISSN 1740-9497

A Simulated Exploration into the Growth of Modern Terrorist Networks

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BSc (Hons) in Computer Science

University of Bath

Spring 2006

A SIMULATED EXPLORATION INTO THE GROWTH OF MODERN TERRORIST NETWORKS

submitted by Steven Butler

Declaration
This dissertation is submitted to the University of Bath in accordance with the requirements of the degree of Batchelor of Science in the Department of Computer Science. No portion of the work in this dissertation has been submitted in support of an application for any other degree or qualification of this or any other university or institution of learning. Except where specifically acknowledged, it is the work of the author.

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Abstract

Increasingly oppressive 'anti–terror' legislation may be viewed as the side–effect of a society that lives in fear. In an attempt to better understand how justifiable that fear is, this study investigates the behaviour of the autonomous terrorist networks indicative of 'modern' terrorism. The Animal Liberation Front is used as an example of a culturally significant organisation from which an extremist force—the Animal Rights Milita—emerges to pose the threat of violence. The technique of agent–based modelling is used to simulate this emergence, and subsequent dynamics, under a variety of conditions. Using a simple grid structure for the agent environment, this simulation not only implements local opinion exchange within a population, but also the effect of mass media, both of which illustrate their significance in range of interesting results.

Who of you by worrying can add a single hour to his life?
—*Luke 12:25*

Acknowledgments

Dr. Joanna Bryson (supervisor) who provided both inspiration and guidance.
Natalie who feigned interest for several months.
My family for being there for me, rather than here.
Helen Mills proof reading.
Dorset LEA for always paying my tuition fees on time.

Contents

List of Tables

List of Figures

Chapter 1

Literature Review

Terrorism, sadly, needs little introduction. The reader may consider for themselves the frequency that this topic features in popular media. If some terrorist act or threat fails to make the headlines, then it will likely be found in the side columns, almost appearing as a trivial matter, and certainly one that is not particularly out of the ordinary. We all know of terrorism and, to varying degrees, most of us fear it.

The prevalence of fear is arguably a greater threat to our society than the terrorism itself. In early April 2006, The Independent chose as its front–page headline, "Helen and Sylvia, the new face of terrorism"(Independent, 2006). The story primarily focussed on two grandmothers, arrested by Ministry of Defence police under new anti–terrorism legislation after trespassing on military property. The story goes on to highlight several similar cases such as that of 82 year–old Walter Wolfgang, famously ejected from a Labour Party conference in 2005 for heckling Jack Straw. He was then briefly detained under the Terrorism Act 2000. Another example is 25 year–old Maya Evans, arrested under the Serious Crime and Police Act 2005 for reading out the names of British soldiers killed in Iraq, whilst standing on the Cenotaph in Whitehall.

Examples such as these, resulting from ever–increasing police powers (most recently the Terrorism Act 2006[1]) may be viewed as the side–effects of a society that lives in fear of terrorism. Increasing numbers of people however, are voicing concerns over a more subtle threat, the infringement of civil liberties. The Independent is certainly not the only newspaper to raise this type of concern either, with similar debates raging throughout media sources on a daily basis.

Non–alarmist and scientific studies into the nature of terror groups—their growth and possible decline—are needed so that we may, as citizens, better question media hype and government spin. These powerful influences perhaps make it all too easy for us to foster an acute perception of threat, and in turn accept civil liberty

[1] This and similar acts can be found through the Office of Public Sector Information, on–line at http://www.opsi.gov.uk. The Terrorism Act 2006 specifically, is at http://www.opsi.gov.uk/acts/acts2006/20060011.htm.

infringements in the name of 'National Security'. Equally, policy makers need to be aware of any evidence that may temper a fondness for further legislation.

Louis and Taylor (2002) observe that 'terrorists are not simply insane'. Perhaps it would be easier for us to write-off terrorists as deranged lunatics, but this rarely seems to be the case. We are forced to accept that those labelled as 'amoral' and 'inhuman' are often anything but. This difficult truth does, at least, provide us with an opportunity. That there is a degree of rationality, implies that there is the strong potential for study. Accordingly, the modelling of terrorist activities is becoming an increasingly popular area of study. The scope of computer software that has been previously used to model all kinds of social network has now extended to modelling terrorist activities.

Individuals and their actions are riddled with complexity. This dictates that attempting to produce a model capable of predicting terrorist action in some way, is unfeasible. But perhaps we may model—as already mentioned—the growth and decline of terrorist groups. Perhaps we may learn from these models something that can be used in the field to support or oppose theories. It may even be possible to assuage the fear that can cause violence to become something of a self–fulfilling prophecy.

In defining the research domain, one runs instantly into difficulties, as the definition of terrorism is highly debatable[2]. A popular source describes terrorism as 'premeditated, politically motivated violence perpetrated against non–combatant targets by subnational groups or clandestine agents' (US Code, 2005). Many will find such a definition rather too simplistic for their analyses, but for the purposes of *our* discussion, this will suffice. Our interest lies in the mechanics of terrorist groups, and more substantial explanations add precious little in terms of functionality. Therefore, let us say that any (subnational) group may be reasonably labelled 'terrorist' if we can see that it is performing premeditated actions which are

a) Politically or ideologically motivated

b) Targeted against non–combatants

c) Violent or destructive, and executed in a clandestine manner

One may wish to argue that the aspect of motivation could be omitted if we are approaching the subject from a purely mechanistic stand–point. Without a discernible motivation though, the lack of organisation within the group would likely obviate any serious terrorist activity. If there were any, then there would still be no rationale nor the possibility of resolution. A collection of sociopaths does not

[2] Whether or not a person or group is deemed 'terrorist', is often seen as a matter of opinion, with a 'battle of words' deciding the outcome. People may wish to consider the moral and legal discussions when defining terrorism, but the largely subjective nature of the debate leaves it prone to constant revision and argument. This is a problem in its own right, and is well beyond the scope of this paper.

seem to lend itself well to organisational study, whereas violence with a reasoned external motivation, does.

1.1 Social Networks and Group Theory

The very essence of social science pertains to interactions of individuals and of groups, and it is therefore not surprising that the structure of social networks has received much attention. In conducting this study, a reasonable grounding in what has been learned of social systems necessary. However, attempting a full review of Social Network and Group Theory would likely constitute several volumes. What we consider here then, are aspects of both which seem particularly relevant to the development of our model.

1.1.1 Motivation

The motivation for an individual to join a group may be complex. However, the strongest motivation seems to be the prospect of involving oneself with other 'like-minded' individuals. Passy (2002) writes that the process of joining in collective action is a long process that sees social networks intervene from the very beginning 'by building or reinforcing individual identities', thus creating 'potential for participation'.

It does not appear practical to spend too much time considering motivation in this study, but we shall regard motivation to be a product of individual ideologies which have not been satisfied externally to the network.

1.1.2 Cohesiveness

In considering how cohesive a group is, I believe that one is effectively formulating a description of its life–cycle. The degree of cohesiveness may govern simultaneously, the attraction of individuals to a group, and the likelihood of members leaving that group. It also affects how the group will react to external stimuli. For example, a highly cohesive group would likely react more strongly in response to a perceived threat to their ideologies, (and ultimately existence) than a group exhibiting low cohesiveness.

1.1.3 Attitudes and Norms

In the context of terror–groups, a theory that has rather alarming implications is that of 'group polarisation'. This is a situation in which the attitudes of individuals become more extreme as a result of belonging to a group. Further to this, we may find that the 'official' opinions of a group are "more extreme than those held by the individual members of the group" (Pynchon and Borum, 1999). This strongly suggests that a person's inclination toward violent protest could easily be exaggerated in a group setting, and the actions of those individuals, or the group itself, could be much more extreme than the intentions any individual had upon joining the group.

Group norms can be defined as the "expected modes of behaviour and beliefs that are established either formally or informally by a group" (Huczynski and

Buchanan, 2001) These norms are of particular interest to a person studying terrorist groups.

1.2 Recruitment

The process whereby individuals become involved in movements through people whom they know, is one of the “most frequently cited facts about social ties and activism”(Gould, 2003). On this basis, the interpersonal relationships that promote membership to potentially terrorist groups, must be a central component in our studies. The topic of clandestine recruitment could excite in the reader, images of personal acquaintances meeting in a dimly–lit room to discuss ideologies, and draw suitable apprentices into their clandestine network.

Whilst such circumstances undoubtedly exist, modernity has had a considerable impact on human interaction. Later, in Section 1.3, we will consider how modern communication capabilities, and attitudes[3] encourage organised protests where, imporantly, like–minded individuals may meet. For now, we shall simply make some basic assumptions about the requirements for ‘recruitment’ where one individual invites another into a group:

- There must be communication (physical or virtual) between both parties.
- There must exist mutual trust between these two, although need not necessarily exist *direct*[4] trust between the new member and **all** existing group members.
- The person being recruited must be known to share the same ideologies as those of the group.
- Based upon the person’s ideologies and other attributes, it should be deemed likely that they would wish to become part of the group.
- The group must **want** a new recruit.

These conditions shall provide a preliminary basis for recruitment into a group. Research suggests (see in Section 1.3) that it is difficult for an individual to insert themselves into a clandestine group, and so we need not consider the situation where this is attempted. That is not to say that such a situation is *impossible* of course, and one often need not look beyond the popular media for stories about the effective infiltration of clandestine groups by journalists or police personnel. However, such behaviour is not the norm.

[3]In less than a hundred years we have seen the advent of the job design theory ‘Scientific Management’ (from its major proponent, Frederick Taylor) and its gradual demise. Social needs—now commonly viewed as the prime motivators—gained importance in organisations and helped create less hierarchical organisational models. Technology had no small part to play in this cultural revolution, aiding the dissemination and assimilation of knowledge on all organisational levels.

[4]Non–direct trust may be through association or reputation for example.

1.3 Terror Groups

Terrorist groups—whilst sharing similarities with social groups of an everyday nature—exhibit traits that are particular to them, and of interest to us. Most important is the clandestine nature of terrorist groups. To a large extent, we need not consider other attributes, such as the ultimate motives of a particular group, because of the magnitude of this distinguishing quality. It is because of this characteristic, (necessary to the survival of the group) that we begin to see real differences in how the group operates—both in relation to the in group, but particularly to the out group.

We are not belittling the motives, or outcomes of terrorist action by denying them a great deal of attention. Rather, we are concentrating upon the most important requirement of terrororist groups—the need for secrecy—and also avoiding a great deal of complexity that would doubtless be incurred if the motive/outcome relationship were explored. It is possible to consider many different groups throughout history, whose motives and methods will be incredibly varied. They will, however, share the same clandestine nature. Indeed, if their actions were not performed in a clandestine manner, then they could not by definition (US Code, 2005) be terrorists.

Whilst all terrorist groups may share common attributes, our emphasis is on *modern* terrorist networks. Indeed, 'networks' provides the first clue as to the modernity of these groups. What we are really considering are terrorist groups that function in a way describable in terms of information–age network designs (Arquilla et al., 2001).

What we witness—by virtue of modern communication possibilities—is a shift from more dated hierarchical structures to radically different, flatter, topologies such as all–channel networks. All–channel networks present a case where each node, or 'member' is directly accessible by all other members. As such, a dense communication network exists. This would previously be seen as impossible to achieve over any physical distance, but modern communications provide a medium which reduces the significance of physical distance. That is not to say that all members will be in contact with all other members, but conceptually there is a significant increase in the *accessibility* of members and ideas.

In recent years, focus has centered predominately on international terrorism. The so–called[5] Middle Eastern terrorist attacks made infamous by the events of 9/11 have dominated public debate during recent years, but we find similar ex-

[5] Whilst the terrorism may well stem from the clash of Eastern belief systems with those of the West, increasing numbers of terrorists actually hold citizenship in Western countries, making it an ideological battle that transcends borders. Turk (2004) believes that much of what has been learned about terrorist organisations is now outdated, and that distinctions such as 'international' and 'domestic' are increasingly meaningless. He attributes this to technological (specifically communication) advances and corporate globalisation that facilitates more flexible organisational abilities. This flexibility often includes the cooperation of 'international' and 'domestic' groups.

amples of terrorist activity—albeit on a smaller scale—arising from 'home–grown' organisations.

This dissertation will use as its main subject matter the Animal Liberation Front, supporters of which sometimes take actions—when operating as part of the Animal Rights Militia—that fit with our definition of terrorism (page 7). As we shall see, this group has a range of qualities that make it an interesting case study from which our model may be constructed.

Animal Liberation Front

The Animal Liberation Front is a trans–global organisation consisting of small autonomous groups. It would be incorrect to say that the ALF is a terrorist organisation, but a few members do perform terrorist acts in the name of the organisation. These extremist ALF supporters move from the moderate environment of the ALF, and become part of groups collectively referred to as the Animal Rights Militia (ARM). It is not clear though, whether the ARM is indeed a separate entity to the ALF (Lutz and Lutz, 2004). What is clear however, is that the ARM groups form from individuals affiliated with the ALF, and carry out attacks in pursuit of ALF goals.

ARM activists regularly claim responsibility for various criminal acts including vandalism, arson and assault. Shockingly, members of the Animal Rights Militia stole—as part of a terror campaign—the burried remains of an 82–year old woman. The deceased was Gladys Hammond, the mother–in–law of Chris Hall who claimed part–owenership of a Staffordshire farm which bred guinea pigs for medical research (Daily Telegraph, 2006). With ARM groups amassing a catalogue of variously extreme offences, one is left wondering how long it will be before the adoption of more mainstream terrorist practices.

The ALF describes a set of guidelines (BiteBack, 2005) by which members should conduct themselves. Interestingly, any group who pursues the goals of the ALF within these guidelines 'have the right to regard themselves as part of the ALF'. Therefore, 'membership' at this level is immediate, and clearly ungoverned. That is not to say that membership to a *terrorist faction* of the ALF is as easy. As with any clandestine group, membership is achieved through close ties and a great deal of trust.

The membership example is, nonetheless, indicative a modern terrorist organisation; there is no centrality to be found here. Instead, what we observe is a loose, non–hierarchical network of autonomous groups which span the globe. Published with the guidelines by which ALF members should operate, are details of potential targets—be they individuals or organisations. Without being given any *specific* instructions, violent[6] ALF members are armed with enough knowledge (guidelines

[6] One guideline is 'To take all necessary precautions against harming any animal, human and

and targets) to engage in terrorist activities, perpetrated to further the ALF's cause. Black (2004) describes terrorists as operating 'underground, possibly alone, though as agents of an organisation'. Such a description seems particularly fitting here, supporting the classification of the ARM as 'terrorist'. To illustrate the ALF/ARM partnership further, Lutz and Lutz (2004) describe the ALF as being able to "present a non–violent image to the general public while still facilitating [terrorist] actions that are effective in shutting down the activities that the group opposes".

ALF activities also provide us with examples of swarming. This is a situation in which "dispersed nodes of a network...converge on a target from multiple directions" (Arquilla et al., 2001). Protest marches and other public demonstrations are advertised on the Internet, and so are capable attracting individuals from and effectively unlimited catchment area.

The ALF has compiled a booklet (Anonymous, 2005) to aid the effective formation of autonomous activist groups. This guide provides us with the following useful information:

1. The **need for secrecy** is—as expected—of particular importance. Further to this, it is made clear that covert groups do not operate in the same sphere as regular ALF members. This information is provided in the line, "Let the public animal rights groups be public, you have work to do that requires privacy".
2. The **creation of new groups** is the norm, as it is highly unlikely that an individual will be able to join an existing cell. Indeed, the covertness of the group is in question if an 'outsider' becomes aware of it.
3. Only **trusted** friends should comprise any new group.
4. Cells ought to consist of **2** to **5** members.
5. Individuals and cells are recommended to perform a number of **less consequential** actions before engaging in actions of a more serious nature.

Due to the nature of the ALF, information on the total number of members is unfortunately unavailable. One is left searching for clues, such as establishing that demonstrations commonly consist of far fewer than 20 people, but may also see a few hundred in attendance.

The reader will not be surprised that to know that ALF individuals and cells must fund themselves. In terms of destruction and loss of life, this is clearly a very limiting factor as limited funds will likely preclude the acquisition of expensive (and so presumably more destructive) technologies. However, budget size does not

non–human'. However, being only a *guideline*, this is occasionally ignored if deemed necessary.

impact greatly upon this research, as I see no particular organisational changes effected by obtaining more substantial weaponry.[7]

The Likelihood of Terror

Many commentaries on the future of terrorism have adopted a rather alarmist position, with levels of rhetoric at least equal to those found in the terrorists' justification of violence[8]. Fortunately, there are those who temper such beliefs with some interesting theories. For example, we may consider the possibility of terrorism dying a 'sociological death' (Black, 2004). This hypothesis is based upon the moderating effect that may be witnessed when people of varying cultures and opinions exist in the same social space, be it physically, or by virtue of modern communication technologies.

Taylor (1998, 2003) also goes some way to assuage fears of increasing violence—although admittedly his study only focuses on 'single issue terrorism' which incorporates environmentalist, animal liberationist, and anti-abortionist groups.[9]

He believes that we will not see widespread terrorism from activist cells which have emerged from the ALF. This belief is based upon a number of ideas which suggest the reduced insularity, and the increased moderation of groups; features which are not indicative of terrorist groups. His work does include an important caveat however, that these suppositions do not necessarily hold for "social conditions characterized by widespread social disruption" (Taylor, 1998, page 27).

Properties reducing groups' propensity for violence (Taylor, 1998, pages 12-17):

1. The power of law enforcers is often exaggerated by environmental radicals, tempering their otherwise revolutionary rhetoric.
2. Radicals do not generally sever ties with family and friends, and so may avoid extreme insularity.
3. In such anti-hierarchical collectives, a 'charismatic authority' will not, in general, be accepted by their peers. Whilst Taylor sees this as a limiting factor of extreme violence, it should be noted that Ackerman (2003) suggests this absence could have the opposite effect due to the lack of a strong moderating voice.

[7]Although probably not resulting in organisational change, the strength of terrorist attacks is significant. If one assumes that more powerful weapons lead to a greater loss of life, and a greater loss of life increases media attention, then various feed–back models may be established. The *strength* of attacks is not to be modelled in this study, although *social significance* is implied from the number of ARM activists in existence (see 'terror gradient' in Section 2.3.1).

[8]Stout (2004) provides an interesting discussion on the psychology of terror, that is, terror as percieved by the general public, and how important it is to reduce panic.

[9]Smith (1998) addresses the problem of single issue terrorism, coming to the rather diplomatic conclusion that, although there are 'real concerns' over the escalation of violence from such groups, an appropriate response should be provided which 'avoids overreaction and remains within the rule of law'.

4. The anti-hierarchical character of the movement provides a venue for debate that has a moderating effect.

5. Open lines of communication—particularly the Internet—reduce insularity of group members.

6. Despite radical opinions, individuals usually involve themselves in issues of a humane or environmental nature because of a strong belief in the sacredness of all life. This makes it very difficult for them to justify the use of violence—even if it is for the ‘greater good’.

Given such suppositions about the nature of single issue terrorist groups, and the guidance provided by the ALF on forming these groups, we may propose a model to represent the formation of radical groups from out of the ALF. It seems sensible to suppose that there is a threshold level at which an individual takes the decision to begin terrorist action. Unfortunately, there is not a body of evidence large or specific enough from which a quantifiable threshold value may be extracted. What we must do, is experiment with different values governing the likelihood of terror until we have a model that appears to be representative of the ‘real world’. When this is achieved, the effect of changing composite variables may be studied.

The application of this study is not limited to the ALF and other closely related groups. Terrorist groups are all afflicted with the requirement for secrecy, and so large terrorist organisations adopt methods akin to those of small teams (Merari, 2001). There is, then, a good possibility that extending our knowledge with respect to small groups could yield benefits for the study of larger groups.

1.4 Modelling Tools

All that we have discussed in previous sections is largely theory. Or at least, in our context has not been shown to hold true. To transform these hypotheses into a quantifiable basis for contention, we require some 'real' environment in which our model may be tested. Presented hereafter—including Section 1.5—are the tools that allow us to go this extra step, and a look at what has been achieved before.

1.4.1 Computer–based modelling

In all kinds of disciplines, it is now common to exploit some kind of modelling technique. Computer–based models allow us to experiment with the outcome of a particular event or series of events in a safe environment. Thus, we may predict what outcome could be expected in the real world. Such a tool is of particular use to physicists, chemists, or indeed anyone else who wishes to reduce the risk factor in their work. It should always be stressed though, that models are imperfect representations of real world scenarios. They have been simplified—sometimes greatly—so that they may be experimented within a discrete, digital environment.

A degree of inaccuracy is typical of these models, since they attempt to discretely represent the boundless complexities of an analogue reality. Despite this loss of expression, the application of these models has since extended beyond simulating chemical reactions and fluid dynamics for example, into the realm of social science. Here, where we find models of population growth, competitive strategy, and the potential spreading of avian influenza (Ferguson et al., 2005), to name but a few.

This extension has required a change in the technique itself, and what we now see are 'agent–based models' which allow complex interaction of 'agents' that are usually intended to represent real people. The use of agent–based modelling techniques has become ever more popular over recent years due in part to increases in desk–top processing power, which allow anyone with a personal computer to model their own artificial societies.

1.4.2 Repast

Repast (Recursive Porous Agent Simulation Toolkit) is a highly–regarded agent–based modelling package that is used by numerous academics for 'developing agents and creating agent environments, as well as initiating, executing, and tracking simulations' (North et al., 2004). It provides a framework so that developers may quickly begin to implement their model, without being hindered by low–level concerns. Repast's application domains are innumerable, but include areas such as cooperative strategy (Axelrod, 1997), altruistic blood sharing among vampire bats (Paolucci, 2003), and the social sciences.

As Repast already boasts social modelling support tools, it is particularly suitable for our purposes. Freely available on most platforms, Repast can be found online (http://repast.sourceforge.net) and is maintained by a body of professionals drawn from government, academic and industrial backgrounds. Several language implementations are now available to create simulations, depending on the user's preference and the suitability of a language to a particular application domain.

For an IDE, or 'Integrated Development Environment' that is easy to use and offers excellent functionality, the reader is recommended to consider the Eclipse SDK, available from http://www.eclipse.org. Eclipse is mentioned again in Section 2.4 because of its synergy with Repast.

1.5 Generative Social Science

In the development of their 'Sugarscape' simulation, Epstein and Axtell (1996) encountered some difficulty in forumulating a term to describe what "sort of science" they were practicing. Since they were defining 'micro specifications' in order to **generate** 'macrostructures', they settled on 'generative' as a suitable type.

1.5.1 Building Blocks for Building Blocs

The history of the amalgamation of computer and social sciences is, in itself, interesting reading.[10] We shall not attempt a chronology of our own here, but it may be necessary to cite historically important developments for example or emphasis.

What is really exciting about modelling artificial societies with computers is the possibility of observing macroscopic phenomena that, in the real–world, may be difficult (and certainly time–consuming) to identify. Epstein and Axtell (1996) define 'emergent properties' as "macroscopic regularities arising from the purely local interaction of the agents". With a well–defined model, we may witness the growth of a society (in which we have defined agents to operate in some specified way) and its emergent properties in seconds rather than years. The beauty of such models lies within their simplicity, as an agent may be defined with only very limited behaviour. Taken at face value, this could seem rather a misuse of time. You may well ask yourself what can possibly be achieved by creating an artificial life that is far more basic than the simplest of life forms. However, what we witness when these agents are allowed to interact with their environment—and one another—is remarkable. Group formation, population trends, and all manner of social phenomena can be instigated with suitable models.

Epstein and Axtell (1996) describe Artificial Societies as requiring three main 'ingredients'. These are:

1. The *agents* themselves
2. The *environment* in which the agents exist
3. The *rules* which govern the behaviour of agents in accordance with their environment and other agents.

As previously mentioned, the application domains of computer–based modelling are wide–ranging. However, we are only concerning ourselves with human societies and, as such, the agents here represent people. Each agent is endowed with certain properties deemed necessary to facilitate an accurate depiction of our subjects. For example, we may wish to consider gender, wealth, or political bias. These attributes could be defined as static or dynamic. One would expect gender to remain the same

[10] See Epstein and Axtell (1996, pages 2-4) for an excellent source of references describing the lineage of computer-based modelling, beginning with von Neumann's 'self reproducing autonoma' of the mid–sixties.

throughout the lifetime of a given agent, and wealth or political bias to change over time in relation to the environment in which the agent exists.

The ‘environment’ may be a simple grid–structure depicting a landscape which the agents inhabit and move within, or perhaps a weighted graph to represent the strength of communication links between agents. Whatever the form, it is this environment that provides the context of our model. It allows us to interpret the agent interactions in a meaningful way so that we may make observations and identify the emergence of macroscopic social processes.

Within our model, ‘rules’ are the ingredient that binds the agents with the environment and with each other. We may need to define a set of rules governing the behaviour of an agent in response to another agent’s proximity, for example. Given a cave–man simulation, it could be necessary then, to program the agent to attack an unknown agent that comes too close. The approaching agent will also have a rule set governing its own behaviour. After all, how else would it have moved toward the first agent? The number and complexity of rules may be arbitrarily large, and random number generation is heavily used.

1.5.2 Representing Terrorist Networks

We can think of a terrorist network as a graph (Carpenter et al., 2002) $G = (V, E)$ where V is the set of vertices, and E the set of edges. Any terrorist t_1 in V may be connected to another terrorist t_2 by an edge e in E. With this idea in mind, we may weight an edge to represent the strength of the relationship between two agents. This is a better representation than a two–dimensional grid, where we are constrained by physical locality. The graph structure enables us to describe something akin to a metaphysical dimension.

The complexity in analysing a network such as this is rather high though, requiring a good deal more processing than a simple grid structure. Whilst this may present a problem on less powerful machines, the greater problem seems to be in visualising a network. Visual representation of a network can help us to understand it better, but we may find in some networks, such as our terrorist one, that the sheer quantity of edges and vertices will produce a very muddled depiction.

A variety of tools available in Repast, such as Sequence Graphs, Data Recording, and snap-shots, may be used to detail the fluctuation over time of various network properties.

1.5.3 Existing Models

We are in a fortunate position. Agent–based modelling of terrorist networks is a new enough field to leave us with plenty of scope for research. However, there is still a substantial amount of research that precedes us, including numerous models representing social systems. Some of these focus directly on terrorist networks

(Krebs, 2002), while others depict very interesting models, which—whilst lacking that particular focus—illustrate many facets of social modelling that are useful to us.

A study of particular importance is 'Modelling Civil Violence: An agent–based computational approach' (Epstein, 2002). In this, Epstein demonstrates how a collection of simple, easily expressed attributes and behavioural rules, can yield fascinating results.

For example, in his model, Epstein evaluates an agent's political grievance as the product of perceived hardship, and perceived legitimacy of the regime. i.e

$$G = H(1 - L)$$

He uses the example of British civilians during World War II to help validate the expression. The perceived legitimacy of the government's call–to–arms against Hitler was high. Therefore, (1 - L) is a small value, and even if perceived hardship is high, then political grievance remains low due to the product H(1 - L).

Political grievance is a very complex notion, so one may be expected to scoff at the credibility of such a simplification. What we find though, is that even this remarkably simple representation is adequate enough to facilitate simulations which mirror real world observations.

One interesting observation was 'Individual Deceptive Behaviour', whereby the regular aggrieved agents did not exhibit a rebellious behavioural state when enforcing 'Cop' agents were nearby. They would, however, turn rebellious as the distance between themselves and the Cops increased. There is nothing unexpected in this behaviour. The likelihood of arrest reduces as the Cops move away, and as such, the aggrieved agent will be more inclined to turn rebellious, because the net risk of doing so is not sufficient to nullify their grievance. To simulate such behaviour as the result of a mere handful of simple ratios is, one must agree, rather exciting.

This was an example of rebellion against some defined authority. In this same paper, Epstein goes on to also model inter-group violence with the same basic techniques, and his example of 'ethnic cleansing' is similarly absorbing.

1.5.4 A Note on Emergence

We have already seen emergent properties defined in Section 1.5.1 as "macroscopic regularities arising from the purely local interaction of the agents", which is a nicely succinct description. The phenomenon of emergence runs throughout our study of generative social science. However, in case it is not absolutely clear, we should emphasise the *importance* of emergence. Gilbert (2002) writes that "emergence is an essential characteristic of social science". In fact, he goes so far as to say that without emergence, a simulation may not be a *social* simulation.

Probably the most commonly visible emergent property is that of clustering. There are numerous studies which deal with clustering, but amongst these, two very well–known examples are 'Modelling Civil Violence' (Epstein, 2002), and a study by Schelling (1969) entitled 'Models of Segregation'.[11] Other emergent properties may be genetic mutation, or natural selection if the model allows these.

So in order to validate our models as providing a social simulation, we seek out emergent properties. To further the realism of a particular social model however, it may be necessary to extend our research to take into consideration how agents react to these properties. The agents should—where necessary—be endowed with a certain degree of self–governance, so that they may chose a particular behaviour, based upon the current emergent features of their environment. We call this 'second order emergence'. Gilbert (2002) explains second order emergence as occurring, "when the agents recognize emergent phenomena, such as societies" and change the rules which govern their interaction with other agents depending on whether or not they are members.

One method of producing this type of feedback is 'tagging' (Epstein and Axtell, 1996, pg. 176). This involves agents possessing tags defining various properties. These may be implemented with a binary string where each position in the sequence represents a property as being present or not present, (signified of course by a 0 or a 1). Parallels can be drawn here to a genetic sequence if it better exemplifies the technique.

[11] In fact, Gilbert—who promotes the importance of emergence, above—used Schelling's work on social segregation to demonstrate emergence in his own study.

Chapter 2

Dissertation

By force of being such an agent he is possessed of a taste
for effective work, and a distaste for futile effort.

—*Thorstein Veblen*, Conspicuous Consumption

2.1 Areas of Research

2.1.1 Pro–Test

At this point, it is sensible to mention a new development specifically relating to the animal rights movement within the United Kingdom. Early in 2006, some time after beginning our research, the formation of a group called Pro–Test gained publicity. Based in Oxford, Pro–Test is a growing body of individuals who publicly support the use of animal testing in medical research. This group has been the focus of much attention, therefore establishing a sort of balance within the media. The actions of those who oppose animal testing are often reported, but now also are the actions of those in favour of such practices. This development has a significant effect upon our model, one that is demonstrated in Section 2.3.1.

2.1.2 Literature Summary

The research conducted in the production of a Literature Review should provide a good basis for progressing with ones own investigations. The most apparent difficulty in producing a concise review, was the large volume of related material. With the social sciences in particular, any number of routes may be taken by the researcher when attempting to formalise even the most basic concepts. As we saw when choosing a definition for terrorism, the complexities involved could be followed indefinitely and, in this context, probably without benefit. It is hoped, therefore, that correct choices have been made when choosing the extent to which any given aspect of the research has been pursued. This cannot be guaranteed, however, and therein lies the difficulty in establishing completeness—as addressed in Section 2.2. If the reader would oblige in assuming that our preliminary research is indeed of an adequate degree, let us then apply this existing knowledge in an attempt to gain further insight.

Several areas have been researched, each providing potentially useful information:

1. **Social Networks and Group Theory**
   Notions of motivation, group norms and cohesiveness were summarised, having been identified as particularly relevant.

2. **Terrorist Groups**
   We have considered the clandestine nature of terrorist groups, and the recruitment process. The Animal Liberation Front has been identified as the focus of this study, as from this group is born the Animal Rights Militia—a single–issue group that meets our chosen definition of 'terrorist'. Further to this, details of the ALF and ARM are more readily available than those of other, more high–profile gorups. The work of some leading thinkers has also been studied, giving varying opinions on likelihood of terror emerging and expanding within these groups.

3. **Generative Social Science**
   The use of computers for Agent–Based Modelling has been investigated, and

seen to be an increasingly popular method of studying social science scenarios. Existing models have been cited, and the concept of 'emergence', fundamental to these models, has been introduced.

On the basis of material evaluated in this early phase, I have chosen to construct a model of the ALF and associated ARM activists. They will exist in an environment populated by many agents who are not ALF affiliated, and the model is to be produced using Repast, as discussed in Section 1.4. The model must in some way resemble the 'real world' and implementation details must be supported by existing work.

The notion of an actual network linking terrorists is to be abandoned in favour of a more basic lattice structure. The complexity involved with representing an entire population, consisting of not only activist and non–activist agents, but also largely autonomous activist groups, is significant. If a network solution could be produced, it would consist of many thousands of vertices and edges—even for a reasonably small population. The difficulty of projecting a coherent visual representation would be even greater. A lattice structure should provide an adequate environment for meaningful experimentation, with the advantage of relative simplicity and clear visual output.

2.1.3 Hypotheses

I hope to demonstrate general support for Taylor (1998)'s belief that we will not see widespread terrorist activity emerging from single–issue groups such as the ALF. Also to be considered is the possibility, from Black (2004), that terrorism could struggle to exist due to the suggested moderating effect of multi–cultural interaction.

The following hypotheses are to be investigated for their *net* effect:

H1. ARM groups will have such limited potential for growth, that restrictions upon their size are arbitrary.

H2. Mass Media influence will encourage the polarisation of groups within a population. This is a logical extension of in–group polarisation, and is supported in Section 2.3.1.

H3. Communicating only with similar agents will lead to polarisation of opinion, and increase the number of ALF supporters turning to terrorism. Group polarisation was discussed in Section 1.1.3.

These hypotheses are intended not to restrict exploration by applying a narrow focus, driven only to argue their validity, but rather direct the research. One may go so far as to say, that an exploratory study should be *expected* to enlighten us in unexpected details.

2.2 Design Fundamentals

Moving from a high level understanding of the terrorist model toward an algorithmic representation presents numerous challenges to the researcher. As with any software development, the usual requirement specification stage commands much attention, and good software development practices should of course be evident. Agent Based Modeling, (ABM hereafter) involves a complication however, that is perhaps not so prevalent in the usual software lifecycle. This complication is the quantifiability of success as a measure of completeness. Unfortunately, completeness in the ABM space—and especially in an innovative scenario such as ours—proves to be a largely subjective measure. How does one quanitify completeness, and what degree of completeness is satisfactory? In the following sections, we address completeness, and the issues of verification and validation—topics of much debate.

2.2.1 Knowing When to Stop

Anyone developing an ABM faces a dilemma: "Do I keep my model simple, or do I make it accurate?" That is a slight exaggeration of course, but it is, in essence, the predicament forced upon those who attempt the computerisation of a complex real world situation.

Historically, ABM seeks to facilitate interesting emergent properties from a very small behavioural set, limited in both scope and function. Many efforts have demonstrated a fascinating coherence with social observations, and have only used the most elementary of operations. However, we must consider whether this approach is always suitable. Analogue to digital conversion, (and vice–versa) in both graphics and audio, is an area of much discussion. Similarly to ABM, there is a compromise between computational viability and high–fidelity reproduction. By modeling a social simulation, we are effectively performing an analogue to digital conversion. The reverse—digital to analogue conversion—occurs when mapping the model's emergent properties to real world hypotheses. Knowing 'when to stop'; when to introduce no further complexity, is difficult, and whilst the traditional ABM teachings advocate simplicity, others such as Kuznar (2005) are in favour of increased complexity. If more complex models result in more accurate results, then it is hard to argue against them. Provided that the computational power is available to support large, high–fidelity models, then the benefits are obvious. The *problems* associated with heavy–weight ABMs appear to be three–fold:

1. Excessive attention to minutiae could potentially result in a model that is over–specialised, and only capable of giving meaningful results for an extremely rare scenario. The researcher may find that rather than create an interesting theoretical test–bed, they have in fact replicated a societal observance with little scope for inquiry.

2. Establishing default values and typical behaviours within the context of an ABM is challenging, and often highly subjective. Each variant therefore introduces a possibility of error. Logically then, a model incorporating many

subjectively defined variants could incur such a large degree of error, that the integrity of the entire model becomes highly suspect.

3. The 'knowing when to stop' dilemma is recursive, and so is applicable at high and low levels. It is impossible to model every facet of a social situation, but how far should one go? Around the advent of ABM, Chaos Theorists pondered upon complexity. Several years later in 1979, they illustrated the difficulty of capturing complexity, with the now legendary assertion that a butterfly flapping its wings in Brazil can trigger a tornado in Texas (Lorenz, 1979). Nearly thirty years on however, the inclusion of butterfly populations in predictive meteorological software remains unlikely. In short, inclusion of further detail is *always* at a cost, but possibly without value.

2.2.2 Verification and Validation

If the reader is unacquainted with these two related topics, then it may be useful to look to the ever–popular description that usually runs along the lines of "verification is getting the model right...validation is getting the right model"(Kennedy et al., 2005). Both of these areas are of great importance to any software designer, and practices surrounding them are often expected to be lengthy and time–consuming. In the case of verification, one may stipulate black box testing, white box testing, regression testing, use–case testing, frequent requirement reviews, and a multitude of other approaches. The validation process may include regular project reviews, participatory design or acceptance testing, plus many more besides.

The challenge of developing a simulation such as ours could be summarised in the following three stages, each riddled with verification and/or validation issues.

1. Correctly interpret a real–world problem at a high level.

2. Translate high–level observations into low–level requirements.

3. Faithfully reproduce the original problem from the specified low–level requirements.

To demonstrate the extent of the V&V problem, let us address these points in turn.

1. Correct Interpretation
   Any given social situation may be interpreted in a range of ways depending upon an individual's own experience, interests and expectations. For example, imagine that a supermarket is seen to have sold out of sausages. An economist assessing the situation may conclude that it is the result of weakened relations with the Danes, triggering a slump in bacon sales, sausages filling the consumer gap. A marketeer may believe that the reason is an innovative new advertising campaign and increased product awareness. Finally, the meteorologist may forecast a heat–wave over the coming weekend and therefore accredit the record sales on people planning barbecues. This stage falls firmly

in the category of validation—getting the right model.

Coming to the correct conclusion is difficult. This is especially so when attempting to explain social models—such as ARM groups—from which one is excluded, and the body of data is minuscule. With sufficient effort however, it should be possible to attempt a reasonable explanation, if only for a limited subset of the total problem.

2. High Level to Low
   At this stage, verification and validation appear to be very closely linked. We are attempting to reduce our high–level mental model into rigid requirement specifications, and as such, risk misrepresentation, and loss of expression. It is here that one must attempt to formally define every notion within the model that has been identified as pertinent, whilst also ensuring that the formal interpretation will match the abstract one.

3. Faithful reproduction
   As Troitzsch (2004) points out, a good prediction may be fundamental in a social simulation, but is "not always a sufficient indicator for validity". If a prediction is made, and subsequently supported by our model, then perhaps there is cause for celebration. Despite such favourable events however, suspicion should be maintained. Perhaps the model was designed such that it could *only* support the prediction, thus potentially reducing its value. It may even be that the original prediction lacks confidence as the result of errors made at an earlier stage. Once again, the researcher is faced with the question of when to stop—this time, when to stop looking for faults.

Kennedy et al. (2005) provide an introduction to the practice of verification and validation particular to scientific and economic models. Here, they are concerned with increasing 'confidence' in the model. One way of increasing confidence could be by approaching a high level of completeness, as addressed previously. The Kennedy et al. paper[1] however, focuses on the practice of 'Docking'. This is a process whereby the output of two separate implementations, (that are attempting to model the same phenomenon) is compared. If similar results are demonstrated, then confidence in the model is strengthened. This practice would exceed our given time constraints though, and will unfortunately not be attempted.

[1] The authors make reference to a chapter by Balci (1998) titled 'Validation, Verification and Testing'. Researchers of a more technical nature may be inclined to read this chapter in full, and indeed the book in which the chapter appears. Those of us less inclined to delve deeply into rather formal explanations, may well be satisfied with the handful of Balci's suggestions as documented by Kennedy et al.

2.3 A Discourse on Modernity

An important aspect of our research, is the influence of modernity upon the growth of terror. We may regard 'growth' to mean:

1. The growth of autonomous activist groups
2. The cumulative appearance of autonomous groups, affecting an overall increase in terror factions within a population.

Similarly, it is necessary to clarify what modernity means to us. In this case, modernity means communications and, in particular, mass communications. We have considered the role of electronic communications within the terrorist sphere. Arquilla et al. (2001) provide an account of modern communications in the formation of terrorist networks, whilst Taylor (1998) lists the Internet as a limiting factor—the open lines of communication reducing one's insularity and therefore reducing the tendency toward terrorist action. The conflict demonstrated here seems difficult to resolve. Effectively, the question is whether technology increases or decreases the likelihood of a person becoming involved with a terrorist organisation. As difficult as it may be to identify cases where individuals have become linked with such organisations through the Internet, it is *impossible* to say how many people have *not* turned extremist because of it.

The uncertainty involved therein is, for our purposes, unacceptably high. Because of this, we shall not differentiate between physical and virtual contact between agents. Instead, a metaphysical environment is opted for, where an individual's neighbours are not necessarily within the same physical locality, but are engaged in some type of relationship. In practice we shall see that 'neighbours' do not always exchange culturally, but this need not skew our perception of the model. I believe that by defining our agent space in this way, we are accepting that both the positive and negative influences of electronic communications are possible, but we avoid dedicating time to an issue fraught with difficulty. For those who believe that the Internet or other modern communication channels encourage group formation, physical separation is eliminated. Anyone who argues that single–issue terrorists maintain links to friends or family (who may, of course express opposing views), will hopefully be pleased that our model allows extremist integration. For example, it is even possible that an ARM activist neighbours a Pro–Test supporter.

Given that the use of modern communications has been handled only implicitly, which facet of modernity is to be modelled explicitly? The answer is this: mass communications, and specifically, the media. It is well documented[2] that terrorist groups often use popular media to draw attention to their plight and actions in a bid to garner support.

[2] Arquilla et al. (2001), Gerlach (2001) and Zanini and Edwards (2001) are just a few sources that acknowledge the important role of media in the self–publicising interests of terror groups.

2.3.1 Representing the Media

Prior to the emergence of Pro–Test, one could have summarised the behaviour of a group such as the ARM in a generically applicable pattern as follows:

1. An extremist group comes into existence.
2. That group wishes to communicate their political or ideological views.
3. Terrorist action is perpetrated by the group.
4. The action is reported in media sources, thus satisfying the goals of the group.

What is shown above could quite feasibly result in a situation where only ARM activity is reported—be it in a positive or negative light. The counter–demonstrations instigated by Pro–Test (note that there is yet to be violent counter–action from this group) add complexity to this media model:

5. An opposing group reacts to the terrorist action.
6. The counter–action is also represented in the media.

If the opposing group is capable of raising its own publicity such that it is equal to that of the original aggressors, then there could potentially exist a situation in which the public are presented with two polar opposites of media influence. It is from this basis that our discussion of media influence progresses, and indeed, it is this dichotomous scenario that shall be modelled.

The mechanics of communication between individuals is an area that is closely related to that of media influence, but one that requires a section of its own, and therefore will not be addressed directly in this discussion. However, there is an apparent over–lap. For example, Deffuant et al. (2000) provide a model for opinion exchange between agents in which a threshold governs whether an exchange is made. If two agents have an opinion that differs by a margin exceeding the threshold, then no exchange of opinion is possible. They call this "bounded confidence". This concept matches my own analysis of the opinion exchange problem. Further to this however, the principle is easily extended to the absorption of mass media. Mckeown and Sheehy (2006) built upon the 'bounded confidence' model from Deffuant et al. (2000) (concerned only with exchanges between neighbours on a lattice), by introducing a second mechanism for mass communication. This mechanism involved the interaction of a *fixed* opinion, representing a media source. An agent absorbs media opinion from a source, but only if the difference in agent and media opinion is within some threshold. As an isolated mechanism, this may be of some interest to the reader. As we shall see later, this however, should not be an isolated mechanism at all. Not only may an agent interact with a media source, it will, in an interesting model, exchange with other agents, thus affecting an indirect media influence throughout the model.

In Mckeown and Sheehy (2006)'s model are also two new variables;

- Polarisation—the degree to which two mass media opinions differ.
- Broadcast ratio—the number of social interactions for each mass media communication.

Now, these variables are of clear importance, and the authors found much to say about them. In other work, Roche (1996) made the poweful statement that "collective violence varies directly with cultural distance". By using polarised media sources, we are synthesising cultural distance, the significance of which is hypothesised in H2, Section 2.1.3. However, ours is not purely an exploration of the polarising effect of mass media. We are concerned with larger issues, and therefore must not focus too heavily upon this one—albeit significant—aspect of the research. With this in mind, the polarisation of media sources shall be set[3], although not studied, and the broadcast ratio is to be abandoned.

The inclusion of two opposing media sources in the model is all very well, but is slightly too limited, even for our purposes. What I propose then, is that a degree of feedback is also in evidence. Let us consider the notion of a what we may call a 'terror gradient' and its effect upon the media presence. We have discussed the importance of the media within the terrorist agenda, observing that it is used as a tool by terrorist organisations to raise awareness of a cause, or influence governmental policy by "inducing fear among their representatives and adherents"(Borum and Gelles, 2005)[4].

It may also be observed that certain norms are established pertaining to the frequency of violent action. For example, a single occurrence of terrorism within an otherwise harmonious society is likely to receive much greater attention than if the same action had taken place in a society more accustomed to such acts. To paraphrase Wardlaw (1982, page 11), when terrorism becomes institutionalised, the perceived significance of terrorist acts is reduced. Wardlaw is in fact refering to terrorism that is institutionalised as a form of government, and his assertion is that terrorism in this case "makes the headlines less often". One sees no reason why government–lead terrorism must be a special case though. If terrorist acts are frequent enough to become 'part of the system', then the "dramatic, newsmaking nature" that Wardlaw cites as a hallmark of terrorism, is removed.

These phenomena strongly suggest that we should not only alter the media presence in accordance to terrorist activity, but also that the degree of presence

[3] In practice, the polarisation will not necessarily be constant between simulation runs. The values of a binary string, representative of the cultural expression of a particular media source, will be set randomly to enhance impartiality. However, the setting of a string's makeup will not be *entirely* random. Currently, the simulation asserts a probability of 0.7 that the binary values will be 0 for one of the media sources, and a probability of 0.3 for the other source.

[4] Borum and Gelles actually consider these goals to belong to the 'first generation' of modern terrorists. They classify organisations such as al-Qaeda to be of the 'new terrorism' variety, who do not simply wish to raise their profile (and accept deaths as a possible side–effect), but actually *intend* to cause loss of life through a range of attacks, some of which are poorly considered and opportunistic

should be proportional to the *relative increase* in terrorist activity from one period to another. This relative increase becomes our terror gradient, and can be calculated like so:

$$\begin{array}{ll} \textbf{if} & A \text{ at } P_0 = q \\ \textbf{and} & A \text{ at } P_1 = r \\ \textbf{then} & TG = r - q \end{array}$$

where A is 'Activity', P is 'Period', q and $r \in \Re$, and TG is the Terror Gradient

Clearly, there could be the situation where we calculate a zero or negative gradient. Similarly, we may calculate a very severe gradient. Either extreme is potentially damaging to our model, and so the gradient must be dealt with sensibly, by being capped at upper and lower bounds, and perhaps implementing a damping equation.

2.4 Design of Test Environment

Paper–based modeling proves to be a useful approach when developing a Repast model from high–level specifications. This method lends itself nicely to the bottom–up ethos that is the corner–stone of agent based modeling. For simple models and prototypes, extending the SimpleModel base class is advised. Those wishing to embark on a more complex model will ultimately find themselves extending SimModeImpl though, which provides more advanced features, perhaps most obvious of which is the easy adjustment of parameters through the user interface. For a discussion of Repast in general and its accessibility to researchers please see Appendix C.

The heavily annotated source code for several popular simulations—included in the Repast installation—allows one to quickly achieve a reasonable understanding of Repast programs. The Eclipse IDE, mentioned in Section 1.4.2, links with Repast nicely, and any good search engine will uncover tutorials such as the one from Gieseler (2004) demonstrating how to properly integrate the two. As well as Repast's built–in how–to guides, a wealth of information awaits the researcher on–line. A strong recommendation is Murphy (2005)'s on–line Repast tutorial, which was found to be invaluable in the development process—particularly in the transition from basic prototype to fully–fledged simulation.[5]

Following the typical division of labour practiced in agent–based modelling, the program is comprised of three classes designed to maintain different areas of the simulation. These are the model, space and agent classes, and are presented in the following sub sections. If, having read this document, the reader requires further information about a particular aspect of the program, then they are directed to the code listing in Appendix B. The program code is heavily annotated, and so should prove enlightening.

2.4.1 Model

The model class is the backbone of our simulation, but it is not that interesting. Let us then address it here only briefly, again directing the interested reader to the code listing in Appendix B.

Although extending the SimpleModel class was adequate for a prototype, the more feature–laden SimModelImpl class was required for the full implementation. This class initiates and manages the simulation for the duration of its execution. It is here that the scheduling of any actions is managed, not only to ensure that each agent is used on every step, but to properly record data to disk, update the display, and perform any other routine tasks.

[5] In an email correspondence, the author tells me that the website address may change in 2006. Also, the tutorial may become out–of–date upon the next Repast release.

The orderly recording of data is also managed within this class. A recorder object is assigned fields of ones choosing in which are stored the matching program variables. This mechanism enables the production of a comma–delimited file from which we may, at our leisure, perform any necessary statistical evaluations.

Of course, the simulation would become somewhat irksome if the user found that they were unable to manipulate program parameters, as this would rather reduce the scope for interactive experimentation. The model class, however, provides such manipulation in a variety of ways, such as direct–entry, check–boxes or drop–down lists.

Although the majority of work involving the agent environment is performed by the 'space' class, it is here that the space is populated with agents, and it is also here that agents may be removed and the space replenished.

2.4.2 Space and the Meaning of Life

The possibility of producing a complex network was rejected in Section 2.1.2 in favour of a lattice–like structure. In fact, this structure is a torus, projected as a 2D grid. Although the physicalities of this agent environment are not particularly interesting, it is important to understand what this space represents. It is not simply an environment inhabited by agents, separated by a physical distance. One believes that this type of implementation would be too limiting. What the agent space actually represents then, is a metaphysical domain. This allows us to model all manner of relationships by eliminating the significance of physical separation, reflecting the pervasion of modern communication devices. We may, for example, imagine two people separated by a huge distance, but who converse at length on a daily basis. In our metaphysical space, these two people can be represented as neighbours, thus facilitating any desired interactions between the pair, without the overheads of edge–weightings that would be incurred in a genuine network model.

Depending upon the reader's disposition, the notion of life and death in our simulation may be viewed as a suitable abstract concept, or perhaps a somewhat murky area. Life for an agent is really the universally shared notion of life: existence. An agent is born into the simulation with certain attributes and behaviours, and also something that slightly deviates from many people's ideas about life and death; a *predetermined* lifetime. A set lifetime is simply a necessary feature to help us simulate life cycles, and so we shall waste no time debating the plausibility of fate.

Death, on the other hand may or may not be death as we know it. In the space defined within our model, the most that death can *mean* to us, is removal from this space. The reader is encouraged to think upon death simply as removal from the modelled society. This could be a result of many circumstances, be it death, 'dropping–out', moving away, or starting a family. Of course, one does not wish to suggest that starting a family means a social death, but as with the other circumstances, it could result in the individual no longer participating at all in the animal rights debate. That of course, is an important point of which to remind ourselves: we are only considering **one** issue. Our model represents only those individuals who are involved, or potentially involved in the animal rights debate. No other issue, and no other individuals, feature in the model.

2.4.3 Agent

To properly understand more detailed discussion pertaining to specific agents, it is necessary to briefly describe the attributes and behaviour of different agents who may exist within the simulation. Each agent is an object within our simulation, and is instantiated with a variety of variables that may or may not be altered throughout the course of the simulation. The following table shows each variable name and its type.

- **x** and **y** are agent's 2D coordinates in the simulation space. These remain constant.
- **law** is the agent's respect for the law. This is a randomly generated integer between 1 and 100 that is set upon creation and remains constant.
- Similarly, **pacifist** represents the inherent degree of pacifism for each agent. Again, this integer ranges from 1 to 100, is set upon creation, and remains constant.
- **isolation** is the measure of an agent's seclusion: the inverse of the number of its neighbours. This will remain constant unless 'life and death' are allowed to operate within the simulation.
- **myGroup** is an integer value associating an agent with any activist group to which it belongs.
- **lifetime** enables the ability to simulate life and death in the simulation. The lifetime for each agent is set to a value between 1 and 200, and is decremented upon each time step. Therefore, when this value reaches 0, the agent may be considered deceased, and removed from the system. The choice of a maximum lifetime of 200 steps was based upon trial runs of the simulation. Over several tests, involving varying parameter settings, it was observed that activity within the model tended to die away at some point not long after 200 steps. It seemed sensible, based upon this observation, that an agent's lifetime is randomly set to a maximum of slightly below this point in order to maintain an interesting, fluid simulation.
- **myDuration** could also be called 'age'. This integer value is set to a low random integer, and incremented at each step. Because our agents are immobile, existing in their metaphysical space, 'myDuration' is more than just age. It is the age of a friendship, and is used in establishing trust between two agents. The longer this duration, in relation to another agent, the more trust exists. 'In relation to', means that the *minimum* of the two durations is taken.

Table 2.1: Agent attributes

Attribute	Type
x	integer
y	integer
law	integer
pacifist	integer
isolation	integer
myGroup	integer
lifetime	integer
myDuration	integer
isAnti	boolean
isALF	boolean
isActive	boolean
CIS	int array

Table 2.2: Cultural thresholds

No. of 1s	Cultural Type	Colour
< 2	Pro–Test	Blue
2 - 7	Neutral	Green
> 7	ALF	Red

- The three boolean flags **isAnti**, **isALF** and **isActive** indicate the cultural state of an agent. isAnti represents a Pro–Test supporter, isALF is an ALF supporter, and isActive is an ARM activist (and also ALF). They are not set permenantly, but vary depending upon an agent's cultural identity string, described next.
- The **CIS**, or 'Cultural Identity String' is an integer array (currently having length 9), that describes an agent's views upon animal testing and related issues for which the ALF fight. Essentially, the more 1s that are in the string, the more closely an agent is aligned to the ALF cause. Thresholds have been set to provide the user with a visual description of the underlying changes. If, for example, an agent has more than seven 1s in its CIS, then it may be represented as a red circle, denoting an ALF supporter.

  Note also, that ARM activists appear as white circles, but are a subset of the ALF and so are not shown in Table **??**.

Although every agent shares basic attributes, their behaviours differ in some respects. This means that the possible states available for an agent to move to may also vary. For example, once an agent becomes an ARM activist, he maintains that state until the simulation ends, or he dies. As Rothenberg (2002) puts it, “Exit...is not tolerated”.

Anti–ALF/Pro–Test

An agent of this type does nothing other than preserve its cultural identity string, and therefore its state. It does this by not comparing CIS bits with any neighbours.

Neutral

Neutral agents possess the greatest behavioural complexity as all states and CIS permutations are essentially within their scope. A neutral agent will assess the cultural identity strings of its neighbours and make one or no alteration to its own CIS based on any findings.

The agent first selects (at random) one of its CIS tag positions. The value in its own CIS at this position is compared to the value at the same position in the CISs of each neighbour, and a counter records how many of these comparisons are a match, and how many are not. If the majority of comparisons result in a match, then no change is made. If matches are outweighed by false comparisons however, the agent switches the value of the chosen tag position to that of the majority.

Note here, that ARM activists are not included in the above procedure. We have asserted that activists require a shield of secrecy, and would certainly not reveal themselves to an individual with no ALF involvement. Therefore, their cultural identity cannot possibly be allowed to factor in the cultural development of neutral agents. If an activist neighbours a neutral agent, then it is effectively skipped–over in the code.

ALF

ALF agents do very little except preserve their CIS. However, if they have the essential characteristics, then they may become an activist either by themselves, forming a new group, or by being recruited by an existing activist agent.

When forming a new activist group without coercion, a factor in the decision—external to the agent’s values—is the prominence of ARM groups. We reuse the concept of a ‘terror gradient’ here to represent the relative degree of ARM activity. This is based upon the assumption that a border–line activist may well be encouraged into action if it is observable, through either popular or specialist media, that action is increasingly common. For this reason, I believe that a gradient is useful here rather than, say, the total number of ARM

Table 2.3: TerrorPlex simulation parameters

Parameter	Type	Entry
Population	Integer	Direct
GridSize	Integer	Direct
RestrictGroupSize	Boolean	Check–box
MassMedia	Boolean	Check–box
NeighbourMethod	Integer	Drop–down List
Range	Integer	Direct
IgnoreOtherCultures	Boolean	Check–box
Respawn	Boolean	Check–box
StepLimit	Integer	Direct

activists.

An ALF member—and similarly with Pro–Test supporters—can be expected to take a greater interest in related media than a culturally neutral individual. Indeed, 'taking an interest' is fundamental to a person becoming part of *any* voluntary organisation, the ALF included. In an attempt to acknowlege this increased attention to related media, the terror gradient value is doubled. One is quite aware that this is a terribly crude approach, and that the doubling is largely arbitrary, as any large increase in the significance of the terror gradient would likely have been just as adequate. However, we have at least began to model this effect, and an extension of this work would see refinements made.

ARM

The one goal of an ARM agent is to recruit members into their group. Neither their CIS nor state is able to change, and therefore exist either for the duration of a simulation run, or (if the respawn mechanism is functional) for their alloted life span. Exactly how an ARM agent attempts the recruitment of other agents is discussed in Section 2.4.7.

2.4.4 Simulation Interface

The Repast framework enables our model, TerrorPlex, to be easily experimented with by a user. A control panel is displayed where several parameters may be manipulated through direct entry (using a text box), boolean check–boxes or drop–down list boxes. These parameter options are detailed below.
Some of these parameters are of an obvious nature and meaning, but others are not. For completeness then, let us briefly describe each one in turn.

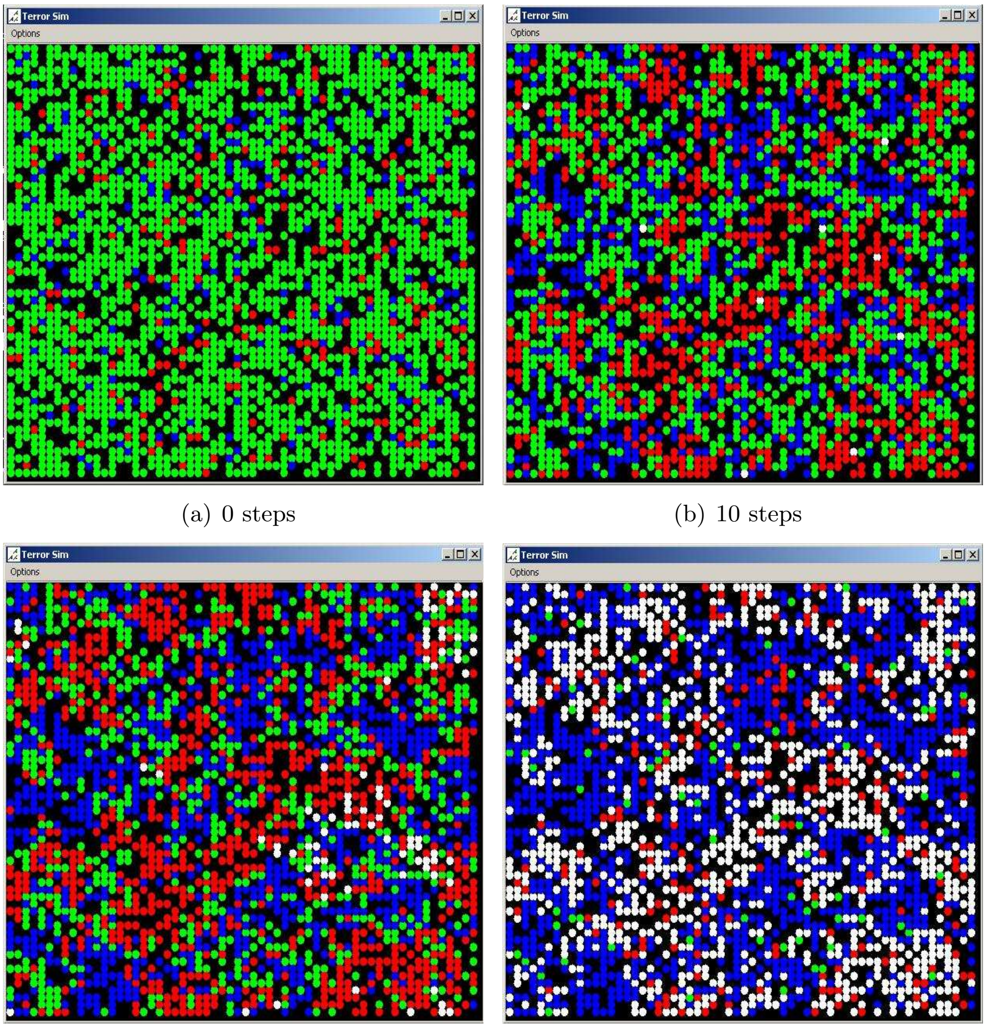
- **Population** is the total number of agents that are to exist in the simulation. This number is maintained when the respawn option is on, and if the user attempts to fit too many agents into a given environment, an informative error message is output, and the simulation stopped. For example, an environment (grid space) of 60x60 units may contain a maximum of 3200 agents.

- **GridSize** is both the x and y dimensions of our square virtual environment grid.
- **RestrictGroupSize** defines the upper size limit of ARM groups. If this value is set to zero, then the number of members of an ARM group is *unlimited*.
- **MassMedia** determines whether or not there is to be mass media influence throughout the model.
- **NeighbourMethod** may either be “von Neuman” or “Moore” and refers to the method by which agents $1...n$ surrounding agent 0 are decided to be neighbours or not. The von Neuman method searches for neighbouring agents in the North, South, East and West directions only, so that given a range of one, the maximum number of neighbours would be four. Moore, however, includes the diagonal directions North–East, South–East, South–West and North–West, potentially yielding eight neighbours when given the same range.
  Although a textual description is displayed, the von Neuman and Moore options are passed in Repast as integers 1 and 0 respectively.
- **Range** is the range of whichever NeighbourMethod is chosen.
- **IgnoreOtherCultures**, if checked, prevents neutral agents from engaging in cultural exchange with non–neutral agents.
- **Respawn**, when checked denotes the implementation of the respawn mechanism, designed to remove old agents from the environment and replenish it with new ones.
- **StepLimit** is the number of internal iterations that the simulation should perform before stopping. Each iteration is effectively a unit of time. A zero value is synonymous with infinity.

Real–time output is displayed in two forms. Firstly, the environment itself is displayed. This is a square on–screen window containing the simulation's agents, which are visualised as small circles of varying colours—the colour illustrating the agent's cultural identity. White denotes ARM activists, Red is ALF members, Blue are Pro–Test supporters and the remaining agents whom we consider ‘neutral’ are coloured green. This display is currently updated upon each internal iteration, or ‘step’, but this may be changed at program code level. The reader unfamiliar with Repast will be interested to know that a movie of the simulation may be recorded, and snap–shots taken.[6]

[6] The Repast implementation used in this research (Repast J version 3.0) stores video clips as .mov files, playable with Apple's QuckTime player. The snap–shots are stored as .png files, and may be taken at pre–defined intervals, upon reaching a ‘pause’ or ‘end’ within the model, or even on demand by clicking the mouse.

Figure 2.1 demonstrates how the environment visualisation may change throughout the course of a simulation, with snap–shots taken at 0, 10, 20, and 30 iterations.



(a) 0 steps (b) 10 steps

(c) 20 steps (d) 30 steps

Figure 2.1: A TerrorPlex simulation: White = ARM activist, Red = ALF, Green = Neutral, Blue = Pro–Test. This particular example clearly demonstrates clustering properties.

The other form of real–time output is a sequence graph (see Figure 2.2. This plots the number of ARM, ALF, Anti–ARM/Pro–Test and Neutral agents against time (in steps). Also plotted, is the number of 'Tag Flips'. This is the number of agents each step that have assimilated part of the cultural identity of their neighbours.

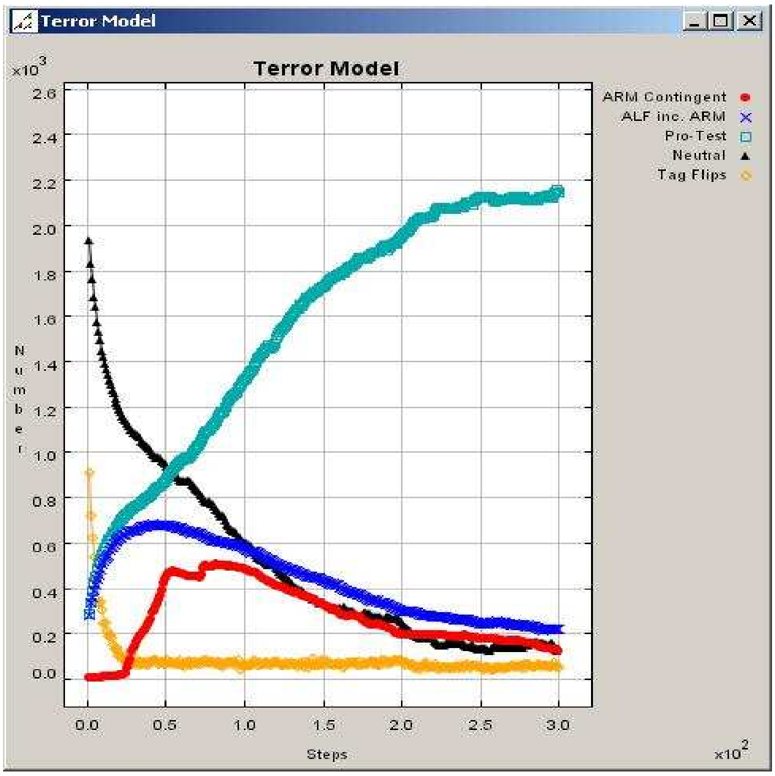


Figure 2.2: Chart output from a TerrorPlex simulation: The total population of each agent type is plotted upon every step. See the key in the top right–hand of the graph to properly understand the plot, as the colours are unfortunately NOT the same as those used in the simulation display.

2.4.5 Opinion Exchange

We have already had an introduction to the ideas put forward by Deffuant et al. (2000) in Section 2.3.1. In their research, they found that for the bounded confidence model, a threshold, d > 0.3 resulted in a uniform opinion distribution, (with the exception of isolated extremists). Conversely, they found that with values of d < 0.3, clusters of opinion were formed. Whilst equivalent thresholds in our model are unlikely to produce the same effects—due to not implementing an identical model—it does at least demonstrate the possibility of interesting properties emerging from the threshold concept. In fact, Stauffer (2005) concludes that if an opinion exchange model is allowed to run for a sufficient period of time, then we should expect to observe one of three possible outcomes:

- Consensus
- Polarisation
- Fragmentation

Mckeown and Sheehy (2006) actually add to these three with a "dynamic regime in which there is a disordered state of opinions". This is almost the opposite of fragmentation. Fragmentation results from there being very little interaction with an agent's neighbours, which makes the formation of clusters rather unlikely. Mckeown and Sheehy's "disordered state" however, can potentially result from extremely *numerous* exchanges, such that the political landscape varies too rapidly for any type of consensus or clustering to emerge. Whilst disordered and fragmented states are inherently different, they seem to be two sides to the same coin; both are fragmented states, the difference being one is static, and the other dynamic. Assessing these states as essentially the same thing may be a remark open to much criticism. However, research (see Section 1.2) stipulates that for terrorist groups to prosper, there must exist a situation in which:

(a) Opinion groups can form.

(b) There exists enough stability to allow the formation of friendships.

For our purposes then, either type of fragmentation should be equally useless.

What must be aimed for then, is either consensus, or polarisation. When considering a collection of models hugely varying in implementation strategies, Stauffer found at least one of these states to emerge in every case. This should be encouraging to any researcher, as it at least *suggests* that interesting emergent properties may be found in any sensible programming solution. What must we do then, to achieve a useful societal state? What is our 'sensible' solution? Having addressed the issue of mass–media influence, the solution lies within a concept already familiar to us. It is, of course, "bounded confidence".

Bounded confidence is a term used to describe the uncertainty of an opinion exchange between two agents. Here, as in the case of our previously defined media model, an opinion exchange does not take place if the difference between two opinions exceeds some thresholds. In terms of our model, this is beneficial as we may stipulate for example, that a Pro–Test supporter can not partake in cultural exchange with an ARM activist. This, the reader will hopefully agree, would be a reasonable supposition to enforce. Through their research, Axtell and Chakravarty (2001) are able to conclude that class norms—once established—are self-sustaining. Now, what they describe as class norms could easily be viewed as cultural opinions. If this is the case, the usefulness of the bounded confidence paradigm becomes clear. Bounded confidence provides a way to make decisions within the model that in turn affect self–sustaining norms—an important property of social systems.

In our model, the cultural identity string associated with each agent defines the 'type' of that agent. A string consisting of mostly zeros denotes a Pro–Test supporter, and mostly ones denotes an ALF member. Agents who fall into neither group may be considered 'neutral' and fair game for conversion to either of the afore mentioned groups. There also exists the special case of the ARM activist. This agent has very particular rules governing its interactive abilities, and shall be described more fully in the next section, 'Recruitment'.

Mckeown and Sheehy (2006, section 5.2) acknowledge that “a more realistic model would have different weightings for mass media communications and social network communications”. It is a small point of satisfaction then to observe that we have indeed produced what they may well believe to be this “more realistic model”. Our simulation implements two separate mechanisms for opinion exchange; one to represent the effect of media influence, and another to manage the local agent interactions more commonly known as “word of mouth”. We have devised a system in which personal exchanges are usually frequent and powerful, and media influence adding richness to the model but being temperamental in strength and frequency. A key feature of this environment is computational feedback. It dictates decision making within the model, and leads to greater cohesion to more correctly mimic, I believe, the complex social situations that we are attempting to make sense of.

2.4.6 Inter–group Exchanges

The reader may be curious at this point with regards to the following two issues:

1. Why do cultural exchanges not take place within Pro–Test and ALF groups?

2. How are group norms established within these groups?

The answer to the first question is this: The opposite ends of the opinion spectrum consist of Pro–Test and ALF groups. They are, in this sense, extreme. The rest of the opinion spectrum is broadly classified here as ‘Neutral’. An agent classed as neutral can be expected to undergo opinion fluctuations as discussed, thus moving to–and–fro between the two opposite extremes of Pro–Test and ALF. Once an agent is in possession of a CIS sufficiently biased as to make that agent a member of one of these two extremes, it can be reasonably expected that an agent remain as part of that group indefinitely. Upon this assertion, we may avoid the large computational overhead of the tag–flipping routine with apparently little loss in realism.

The second answer is of a similar vein. It is uncertain whether, in this situation, there would be polarisation or moderation within a group. In the interest of simplicity, and because our studies do not focus on this aspect of group dynamics, the role of group norms have been eliminated. If our work were to be extended to involve cliques and other small groups within the ideological groups represented here, then further investigation would be necessary. The current scope however, does not require this extra complexity.

2.4.7 Recruitment

The process by which agents are converted to activists, is central to our studies. Working from the ALF guidelines presented in the literature review (page **??**), recall that potential ARM members must be recruited by an activist already operating as part of an activist group. This of course begs the question, how does *any* ARM group come into existence? Quite simply, new ARM groups are born out of—in our model—a highly unlikely combination of variables. Although unlikely, this combination of variables is occasionally produced, and when it is, an agent is transformed into an extremist. In our model, extremists are intent on building a new ARM group through the recruitment of like–minded individuals.

A key behaviour to note is the probabilistic difference between being an instigator and being recruited. An agent needs very particular properties to initiate the formation of a group. These properties form what we call an agent's 'tendency', or in full, its 'tendency toward violent action'. This is ascertained from a calculation in the form of:

$$Tendency = Isolation \div (Law \times Pacifism)$$

Where 'tendency' is a numeric value that falls above or below some threshold, 'isolation' is a measure of how few neighbours an agent has, 'law' is that agent's respect for the law, and 'pacifism' is a measure of the agent's inherent peace–loving nature.

Given the above equation, it is possible to see how many different combinations could lead to a high tendency toward violence. For example, although an agent may be not at all isolated, it could have little respect for the authorities, and a propensity for violence. Conversely, an agent could exaggerate the power of the law—as Taylor (1998) implies ALF members do—and be of a very peaceful disposition. However, a high degree of perceived isolation may skew their usual nature and lead them to form an activist group.

Despite there being many permutations of personal attributes that may lead to a reasonably high tendency, the necessary limit in our model is set *very* high in an attempt to reflect the supposed[7], rarity of such individuals. Of course, an agent must also have ALF beliefs if they are to become an ARM activist. We are not concerned with those who have a high tendency toward activism but are not of ALF belief, as they have no bearing on this single–issue model.

Having dealt with the difficulty of taking the first step in the formation of an activist group, we may now look at the process of recruitment. Membership to an existing group comes only through recruitment—as discussed during our research—and is therefore absolutely vital if we are to create an interesting simulation. To recap, let us list several conditions—as proposed in Section 1.2—that must be met in order to successfully recruit an agent:

1. There must be communication (physical or virtual) between both parties.
2. There must exist mutual trust between these two, although not necessarily between the new member and **all** existing group members.

[7] One source suggests that the proportion of the population suffering from "anti-social personality disorder" could be as high as four percent (Stout, 2005). That is, one in twenty five individuals could be a sociopath. Remember though, that we are pressuming the (majority of) terrorists to be sane. These two details suggest that the proportion of individuals psychologically capable of instigating an activist group should be significantly more than four percent.

3. The person being recruited must be known to share the same ideologies as those of the group.

4. Based upon the person's ideologies and other attributes, it should be deemed likely that they would wish to become part of the group.

5. The group must **want** a new recruit.

Addressing each one of these in turn, we shall demonstrate how the conditions relate to the actual simulation model and specific agent attributes.

1. Communication is equally possible with each of an agent's neighbours. An agent's 'neighbours' are those agents that fall within a certain are surrounding that agent. The area is defined with a combination of method—be it Moore or von Neuman (see Section 2.4.4)—and range, which are both user–settable parameters.

2. Trust is an incredibly complex notion[8] and any in–depth discussion is, regrettably, far beyond the scope of our research. It is, nonetheless, a necessary attribute of any subversive group, as the utmost secrecy must be maintained at all times. What I have chosen to implement then, is a somewhat crude, but reasonably effective representation of trust where the strength of this trust is directly equated to time. Simply, the duration for which an agent has been the neighbour of another agent, represents the level of trust between the two. If the duration exceeds a threshold, then we may say that there exists a mutual trust. If the duration does *not* exceed the threshold, then the agents may well communicate culturally with each other, but do not share a level of trust sufficient enough to engage in any discussions pertaining to—in this example—illegal activity.

   Also, it is not required that a yet–to–be–recruited agent be trusted by every member the group of which the recruiting agent is a member. Here, trust is said to be commutative. If this were not the case, it would be extremely difficult, if not impossible, for activist groups to form, as each member would have to exist within one very small cluster of individuals. Even if a group was able to form under such conditions, it would be a rather dull example, since the possibility for growth or indeed any change (except perhaps a reduction in size due to death or arrest) would have been eliminated.

3. In reality, a person's opinions and personal attributes are not stored—as they are in our model—in the form of publicly available values. However, human beings have become reasonably adept at assessing another's values through

[8]Sztompka (1999) has written a rather interesting book entirely dedicatated to a sociological theory of trust. He defines trust as "a bet about the future contingent actions of others", which is especially appropriate in our case, since activists must *trust* an individual not to reveal their criminality should a recruitment attempt be made. This, one may imagine, is something of a gamble.

contextual, conversational, and visual clues. It does not, therefore, require a great stretch of the imagination, to believe that it is realistic for one agent to be effective in determining the ideological persuasion of another. It is even acceptable to omit the probable error involved since, if necessary, it is always possible to simply *ask* a real person for their opinion, and it is likely that someone with a strong belief will do little to hide it. Clearly, this is not true for every type of belief (racists may do well to keep their opinions private), but supporting the ALF cause is in no way a crime and need not be hidden in the same way.

The thoughtful reader will find fault with this last statement, pointing out that an ARM activist is possessed of ALF ideologies, but would not be willing to make this common knowledge lest their secrecy be compromised, (recall the ALF guidebook's advice to, "Let the public animal rights groups be public, you have work to do that requires privacy" Anonymous (2005)). Be assured though, that the simulation includes an instruction to remove existing activists from the scope of the recruiting activist, thus avoiding this awkward situation. This produces the side–effect that an agent is limited to involvement with one group at a time. Note however, that there is insufficient information available 'from the field' to say whether exclusive membership is a reasonable supposition, and will be presented later as an area for further study.

4. It is one thing to establish a person's ideologies, but quite another to make a reasonable assessment as to whether they have the suitable qualities to be recruited into a dangerous and highly secretive group. The risk of exposure following a failed recruitment attempt is unacceptable. As far as possible, a group must be sure that an individual will accept a proposition of membership. Again, this is not a straightforward task for the recruiting agent. However, we may exploit our definition of trust in order to make such error–free fact–finding justifiable. As we have said, trust must exist between two agents for recruitment to be possible, and trust is equated to the duration over which the two agents have been neighbours. This notion of time implies knowledge: it is reasonable to expect the knowledge of one person about another person, to increase over time. If an agent in our model has been the neighbour of another for a sufficient duration as to allow trust, then one would expect the duration to also imply that a measure of detailed knowledge would have been accumulated.

5. It would be an odd situation indeed that causes a group of *any* kind recruit unwanted members. Also, our research shows that ARM groups are recommended to be of a small size, ranging from 2 to 5 members. The distribution of group sizes are of course, unknown to us. We therefore opt for a simple random distribution of size. Whenever an activist is spawned—constituting the first member of a new group—the group's size is changed from 0 to 1. The situation thereafter is only slightly more complicated.

> So a group is to have a preferred number of members, but that number is not to exceed five. Would it be reasonable to set the preferred number of members permenantly? I do not believe so. At one time, a group may feel that three are enough, but at another time, perhaps circumstance dictates the maximum of five. What is more, a group may be happy with just three, but is so impressed by a potential recruit that they make an exception and expand their size to four. Effectively, activist groups may grow on a time/case basis.
>
> Implementing this type of case is simple. When an existing activist agent looks to recruit another, (who has been deemed a suitable candidate), the system generates a random number between 2 an 5. If the size of the group is already greater than this number, then the recruitment attempt is abandoned. If, however, the group is currently smaller than the generated number, then a check is also made to see that the group size does not currently exceed four. If this is also passed, then the recruited agent becomes an activist group member, and the group's size is incremented by one.

If inclined to evaluate a slightly different model, the reader is directed to an interesting paper on "Emergent Clique Formation in Terrorist Recruitment", Berry et al. (2004), which uses the Afghan mujahedin to illustrate the method. In this are described two types of agent: an 'expatriate' and a 'bridge'. The expatriates are similar to our ALF supporters, and the bridge agents may be equated to our activist agents, promoting terrorism. In their model however, it is not individuals but entire cliques that are recruited. An established clique must have its 'disgruntlement' (calculated as an average of disgruntlement over all members) pass some threshold in order to become susceptible target for conversion to terror. Despite the functional differences, the concept of thresholds and influence remain, and the authors introduce a further interesting classification: abstract agents. Expatriate and bridge agents are individuals, but abstract agents are representative of collections of individuals. As such, the clique is an abstract agent. The idea of an abstract agent is extended to include mosque, city and society, in an increasing abstraction. The abstract agents are not just representations of collectives though; they may also communicate between each other and individuals. The inclusion of similar abstractions in our own studies should definitely be an area of further research.

2.5 Design of Experiments

Detailed in Section 2.4.4 were the variables accessible to the user for manipulation. That each variable may be set by the user is a reflection of their potential importance. However, to avoid extensive experimentation, some have been identified as perhaps more relevant—more interesting to us—than others. For example, the ability to enrich the simulation with virtual 'Mass Media' is perceived to be highly relevant. The option to select either a Moore or von Neuman neighbourhood is also made available to the user, but expected to be a matter of taste rather than an area of primary experimentation.

For our purposes, the pertinent options that may comprise our independent variables are:

- Ignore Other Cultures
- Mass Media
- Restrict Group Size
- Respawn

2.5.1 Primary Experimentation

The 'Respawn' option is one that we shall address in the next sub–section, but will for now be assumed to remain in its default unchecked state. What remains, therefore, are three variables which result in eight permutations as described in the following table.

The table shows permutations divided into four primary groups, (A, B, C and D) by the combination of 'Ignore Other Cultures' and 'Mass Media'. These are then subdivided by the addition of 'Restrict Group Size' as another factor, thus necessitating classification by a letter and a number, such as A1, A2, B1, B2 and so forth.

Table 2.4: Experiments matrix

Ref	Ignore Other Cultures	Mass Media	Restrict Group Size
A1	Yes	No	Yes
A2	Yes	No	No
B1	Yes	Yes	Yes
B2	Yes	Yes	No
C1	No	No	Yes
C2	No	No	No
D1	No	Yes	Yes
D2	No	Yes	No

If we are to make any claims on the basis of our results, then we must have a degree of confidence in our results. Confidence in terms of validation and verification has already been discussed in Section 2.2. What is considered here is confidence in terms of repeatability. This type of confidence requires us to perform the same experiment a number of times and to produce a similar data set from each. Generally, being unable to reproduce similar results between tests means that our confidence in the predictability of the outcome is reduced to zero, and one would be foolish to support or deny any hypotheses.

It is difficult to decide upon the number of times that each experiment should be repeated. Ideally, one would repeat an experiment a large number of times, but experimentation takes time, and time is often at a premium. Further to this, I do not believe that a large number of repetitions is in fact necessary. Because of the inherent randomness in this simulation, there is 'noise': identical experiments will not—in all probability—progress in exactly the same way. Even if each simulation produces *almost* identical data sets, they will never be *actually* identical. With this in mind, a sufficient number of runs must be undertaken with the aim to reduce perceived appearance of noise. Also, the researcher must remember that others will require more convincing than themselves, and so should set the number of repetitions comfortably above what they require for their own satisfaction.

The results presented in this document are all obtained—unless otherwise stated—from 15 repetitions of the same experiment. The behaviour of the exeperiments does not vary greatly between runs, and so a low number of repetitions is justifiable. One would doubtless suffer a few withering looks if it was claimed that 15 was the 'correct' number to settle on; it cannot be claimed to be anymore 'useful' a number than 16 or even 14. A choice had to be made however, and 15 repetitions provides what seems to be a reasonable compromise.

Confidence in each 'run' of an experiment must also be high, and ensuring this requires similar reasoning. It must be decided then exactly how many internal iterations or 'steps' constitute a complete run. From performing trial runs, it has become apparent that the approach for deciding this limit—called StepLimit in our model (see Section 2.4.4)—varies depending upon whether the respawn parameter is set to true.

If respawn is 'off', then the agents that are propagated at the beginning of a simulation run, remain in existence until the simulation ends, and no other agents exist at any point between beginning and end. The simulation, in this sense, is closed. Under these conditions, we observe that the simulations eventually stabalise, and each agent maintains its current state indefinitely. If it may be confidently asserted that nothing more will happen after a particular number of steps, then we need only record data up to that point. Most of the primary experiments (the ones that do not involve respawning) are recorded up until 400 steps as, by this point, interesting behaviour has stopped. However, the reader should be aware that the results of experiments B1 and B2 required a simulation period of 800 steps to properly illustrate the behaviour.

Enabling the respawn option means that the simulation is unable to settle at an exactly constant state as agents are constantly removed from, and added to the simulation. At first sight then, setting a step limit under these conditions seems somewhat impossible. All one need do though, is recall that we need only concern ourselves with 'interesting' behaviour. What transpires, is that after a particular number of steps (or thereabouts), aspects of the simulation (the number of ALF agents for example) fluctuate about some value. At this point, despite the randomness and fluctuation, the simulation is no longer interesting as it is simply maintaining flux. Again, if one can confidently assert that nothing more will happen after this point (aside from the maintaining of flux), then a step limit has been decided.

2.5.2 Secondary Experimentation

The secondary experimentation involves the use of our 'respawn' mechanism, which is designed to avoid the model stagnating, by constantly removing and introducing agents. The variation of results when using the respawn option is quite fascinating, and it is certainly worth discussing some of these. However tempting it may be though, to make extensive use of respawning in the model, for example by repeating experiment pairs A through to D with respawn 'on', such an investment of time is to be avoided. It may appear slightly odd to shy away from such interesting work, but we must remember that the respawn mechanism is extremely limited. Although it succeeds in keeping simulations 'live', one cannot possibly claim that it faithfully represents the real world. Three major flaws should be noted:

1. Agents are removed at random.
   Removal of an agent occurs when its lifetime expires, and the lifetime is a randomly–generated value. Recall that the agent space is a metaphysical arena representing the proximity of agents at the social level. It is not unfeasible to imagine that different cultural groups may, for whatever reason—be it circumstance, or loyalty for example—maintain these relationships for varying durations. Indeed, given that strong social bonds are required to form ARM groups, it is probable that the duration of the relationship between these individuals will generally be longer than that of ALF supporters perhaps only connected through newsletters and the Internet.

2. Agents are introduced at random.
   New agents are composed of randomly–generated attributes, and placed at randomly chosen available position in the agent space. For reasons similar to those concerning the removal of an agent, this implementation is unsatisfactory. The simulation allows all manner of potentially nonsensical situations. An ARM agent could be introduced into an a social space dominated by Pro–Test agents for example. However, it is difficult to say that a scenario

similar to this is really that improbable. Throughout this research, it has been suggested that devices such as the Internet facilitate communication between culturally variant individuals, and we have also noted that single–issue terrorists do not usually sever ties with family and friends. With these factors in mind, intermixing of cultural types is perhaps acceptable. Much more research is required here though.

3. No feedback.
   There is no attempt at simulating any kind of generational feedback in the model. For example, where a consensus is evident, with the vast majority of agents being of a particular cultural identity, it would be reasonable to expect a bias when introducing new agents. One approach may be to increase the likelihood that the new agent will share the cultural identity of the consensus group. This element of social feedback is, however, beyond the scope of our studies.

It is suggested that these areas of deficit be addressed in further work so that the results of a respawning model are possessed of greater confidence. In this study, however, no attempt is made to improve the mechanism and, for this reason, it would be unwise to perform time–consuming analyses. Despite a lack of completeness, some of the results are so interesting that it would be a mistake to ignore them completely.

2.5.3 Recording Data

Repast provides good support for the recording of data, and this is relied upon to create a comma–separated text file for use with statistical software. The basic format of this file is:

Run, Step, Seed, ARM, ALF, Neutral, Anti, Flips, TGrps, TGrad

Where *Run* is the current simulation number when in Batch Mode, *Step* is the model's internal iteration count, *Seed* is the random seed user, *ARM* is the total number of ARM agents, and similarly for *ALF*, *Neutral* and *Anti*. *Flips* refers to the number of agents during the last step that assimilated part of the cultural identity of their neighbours, *TGrps* is the number of ARM groups currently in existence, and *TGrad* is the 'Terror Gradient' as defined in Section 2.3.1.

The format of this data file may be easily modified at code level, and Repast's scheduling mechanism provides the ability to record values not just at every step as we have done, but at user–defined intervals or at other events.

Chapter 3

Results of Experiments

This chapter documents results from the experiments described in Section 2.5. In order to limit repetition, the results are briefly described in the following pages, but the reader should look to the analyses of Chapter 4 for coherent explanations of simulation behaviour.

The comma–separated data file produced with Repast is a format understood by all good statistical software. This project used the statistics program SPSS to extract, sort, and interpret the data.[1]

For brevity, some sets of graphs have been removed from the following section and placed in the relevant appendix. This is done when a set of graphs from one experiment is particularly similar to those of a related experiment. The reader is informed when this case arises, and may look to the appendices for confirmation.

In the following subsection are groups of four graphs, presented together as one figure. These plots consist of a central line, and error bars either side of this line. The central line is the mean value at that point, and the error bars represent a standard deviation of 1.0.

[1]The version of SPSS available to the author, (ver. 10) was found to be somewhat frustrating and prone to errors, but mostly provided the required functionality. SPSS can be found on–line at: http://www.spss.com.

3.1 Results of Primary Experimentation

In an attempt to keep figure captions reasonably short in the table of figures, acronyms have been used when referring to the following presentations. The option to "Ignore Other Cultures" is represented by "IOC", and "Mass Media" becomes "MM". Thus, the caption for Figure 3.1, which reads "A1: IOC no MM, restricted" indicates that the graphs are for experiment A1, where the IOC option is on, MM is off, and ARM group size is restricted to the default value of 5.

Please note that the simulation was written before Pro–Test came to prominence, and so the more general term of 'Anti' is used in the following graphs, which is synonymous with 'Pro–Test' as used throughout this document.

3.1.1 A1: Restrict Group Size

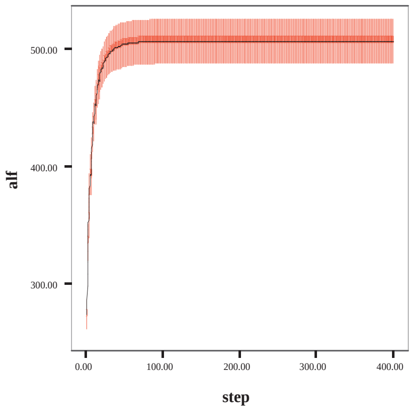
Experiment A1—and similarly with A2—have the 'Ignore Other Cultures' option selected, but not mass media influence. A1 sees the 'Restrict Group Size' parameter set to 5.

The population is heavily fragmented, with the majority of agents remaining neutral. ALF and Pro–Test groups are of an approximately equal distribution, and the occurrence of ARM is very limited.

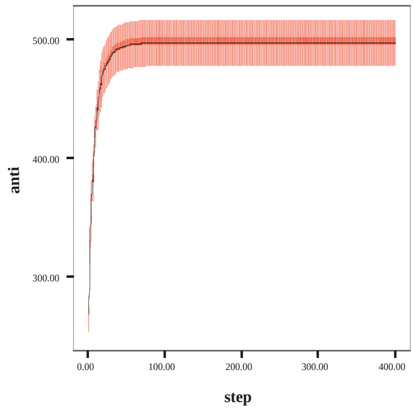
3.1.2 A2: No Size Restriction

Without imposing a size restriction on activist groups, a much higher percentage of ALF members are recruited into ARM groups. The plots are very similar to those in Figure 3.1 and have therefore been relegated to Appendix A.1. The exception of course, is the ARM plot.

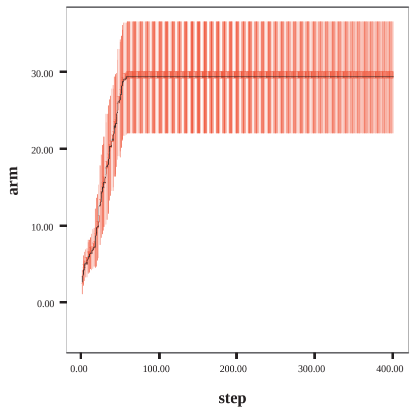
Comparison of figures 3.2 and 3.3 show that the distribution of ALF, Neutral, and Pro–Test agents remains much the same in each experiment. However, the *majority* of agents with an ALF culture have, in Figure 3.3 become ARM.



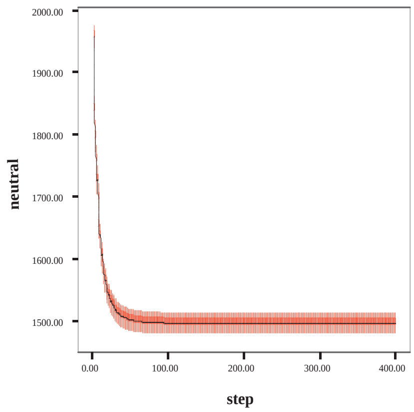
(a) ALF



(b) Anti



(c) ARM



(d) Neutral

Figure 3.1: Experiment A1. Agents ignore other cultures, there is no mass media, and ARM groups are restricted to five members.

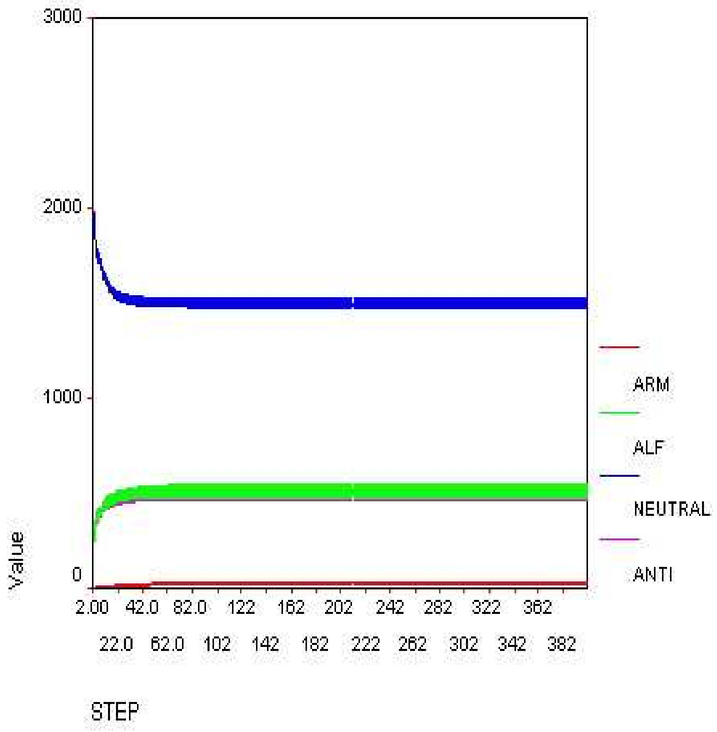


Figure 3.2: A1 overlaid plot. Notice that the proportions of ALF and Anti agents are so similar that the Anti line is almost completely obscured by that of ALF.

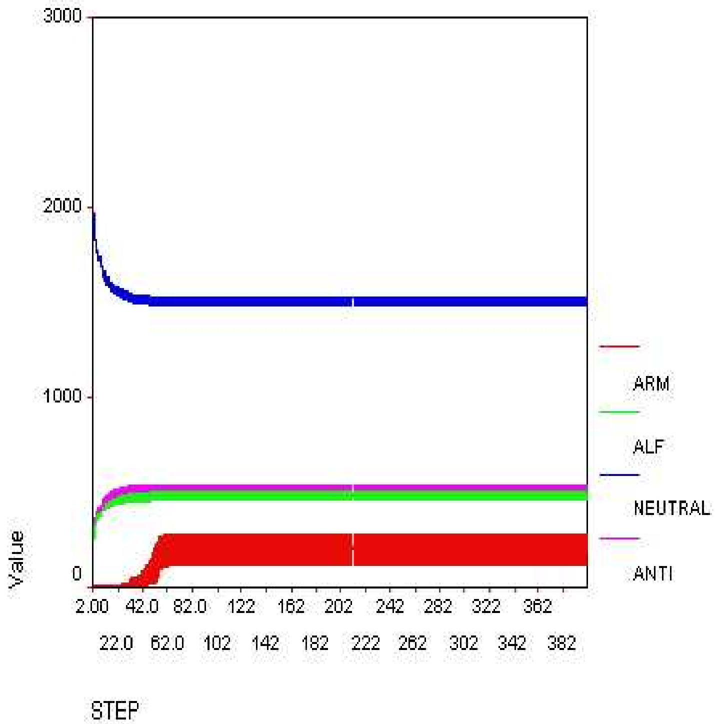
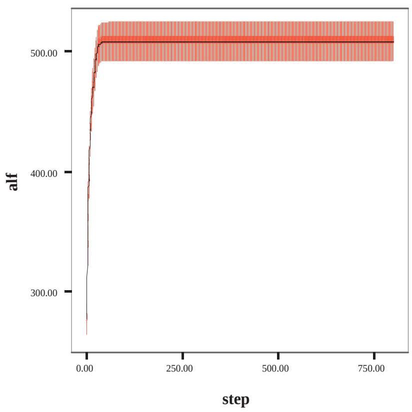


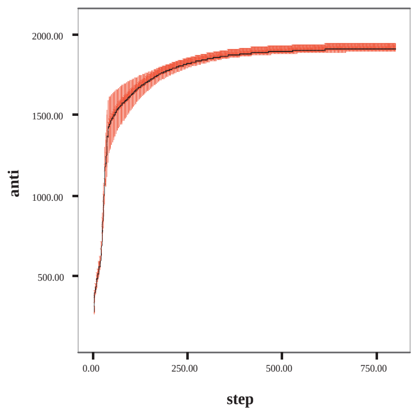
Figure 3.3: A2 overlaid plot. As with A1, but no restriction on the size of ARM groups. This is almost identical to Figure 3.2, except that many more ARM agents are shown to be in the simulation.

3.1.3 B1: Restrict Group Size

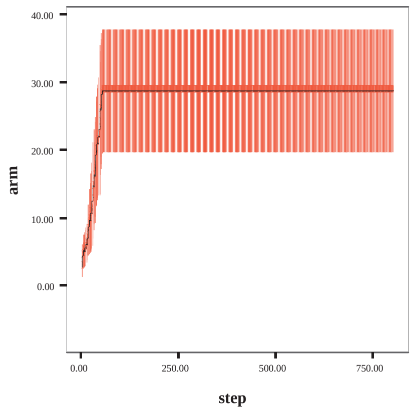
The experiment pair B1 and B2 have, as in A1 and A2, the ‘Ignore Other Cultures’ parameter set to true. However, mass media influence is no also active. This first experiment of the pair has the ARM group size restricted to the default of five members.



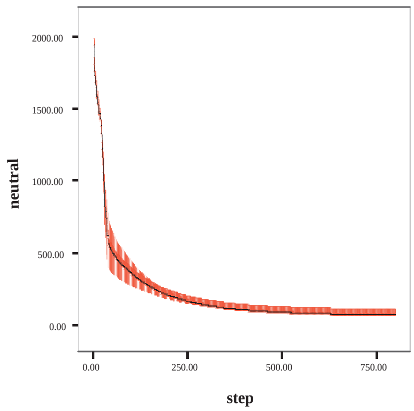
(a) ALF



(b) Anti



(c) ARM



(d) Neutral

Figure 3.4: Experiment B1. Agents ignore other cultures, mass media is used, and ARM group size is restricted to five members.

Initially, Pro–Test and ALF membership grows at a similar rate. At 20 steps however, ALF membership peaks, and remains constant while the number of Pro–Test agents grows rapidly for a time until it begins to plateau. The significance of exactly 20 steps shall be explained in the analysis. After approximately 600 steps, the model stagnates leaving the majority of agents in the Pro–Test state. A notable proportion of the agents are ALF, but very few of these have formed ARM groups.

Also notice that there are close to zero neutral agents. This model provides a good example of a majority consensus.

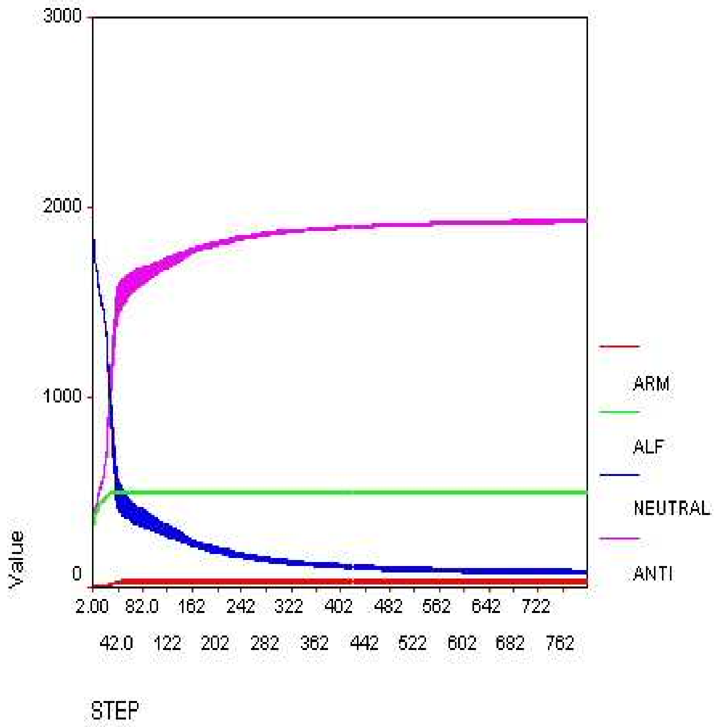


Figure 3.5: B1 overlaid plot. Shows reflected Anti and Neutral lines, with a mostly constant ALF population.

3.1.4 B2: No Size Restrictions

The effect of lifting group size restrictions is very much like the one observed in experiment A2. The overall behaviour and ultimate composition of the population is largely the same as in B1, hence the quad–plot figure is to be found in Appendix A.1. However, the ARM contingent is allowed to grow unbounded in this instance, and approximately half of the ALF population is recruited.

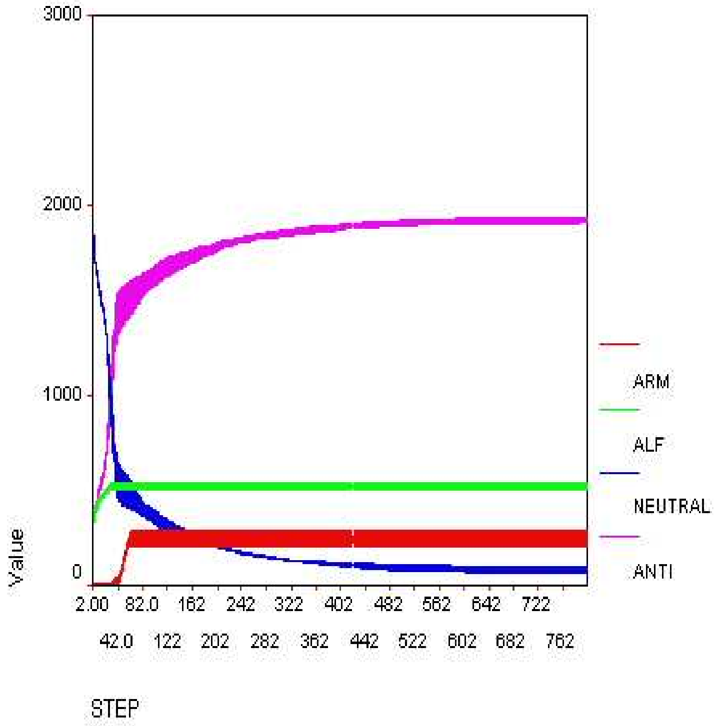


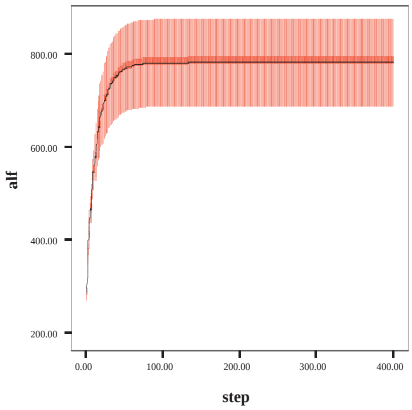
Figure 3.6: B2 overlaid plot. As with B1, but no restrictions on ARM group size. Due to this, there is a ARM population noticeably higher than in Figure 3.5.

3.1.5 C1: Restrict Group Size

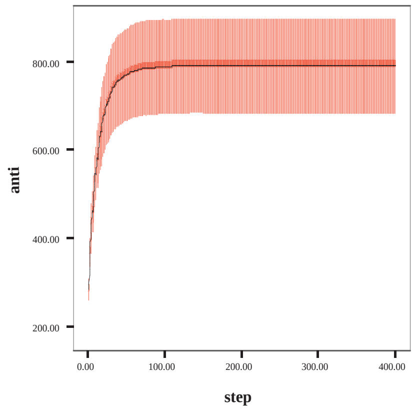
Mass media does not feature in the pair C1 and C2, but with neutral agents no–longer ignoring other cultures, experiment C1 provides an excellent example of clustering within our population. ALF and Pro–Test clusters form, but there also remains a large proportion of neutral agents. In fact, the distribution of these three cultural types is reasonably equal. Out of the ALF clusters we find that ARM clusters also emerge, although these are few and small.

3.1.6 C2: No Size Restrictions

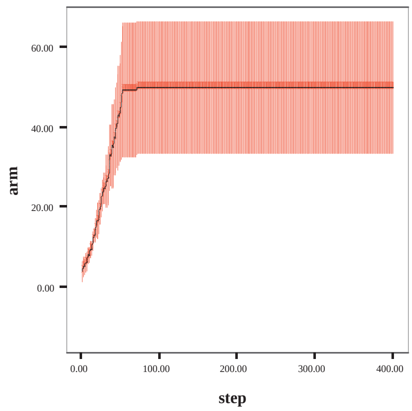
As with C1, but nearly the entire ALF community recruited into large ARM groups now that the restriction on group size has been removed.



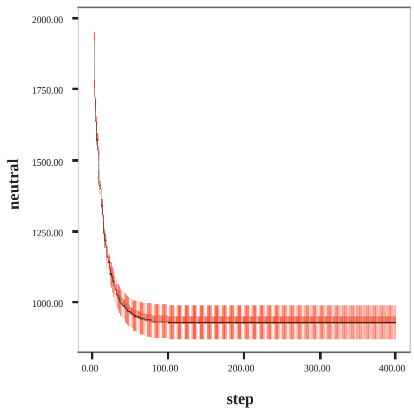
(a) ALF



(b) Anti



(c) ARM



(d) Neutral

Figure 3.7: Experiment C1. Agents do not ignore other cultures, there is no mass media, and ARM groups are restricted to five members.

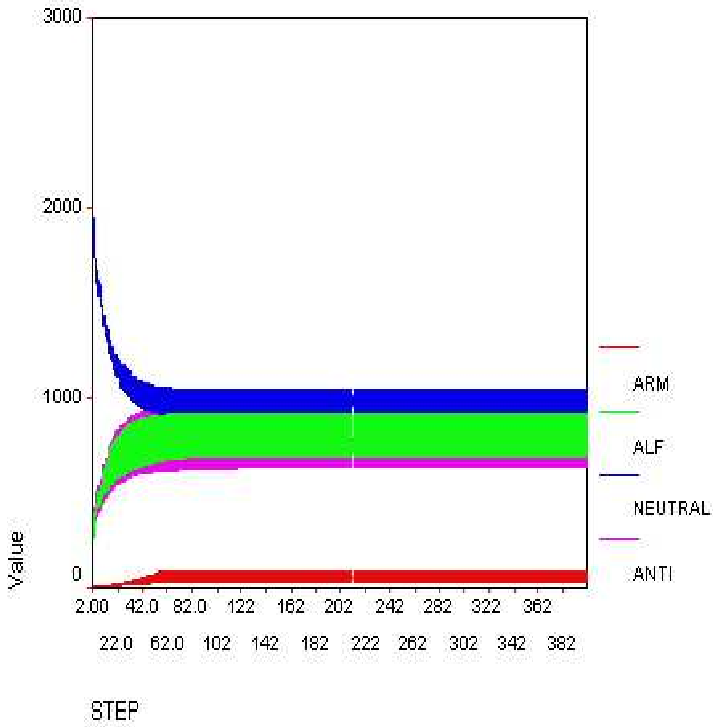
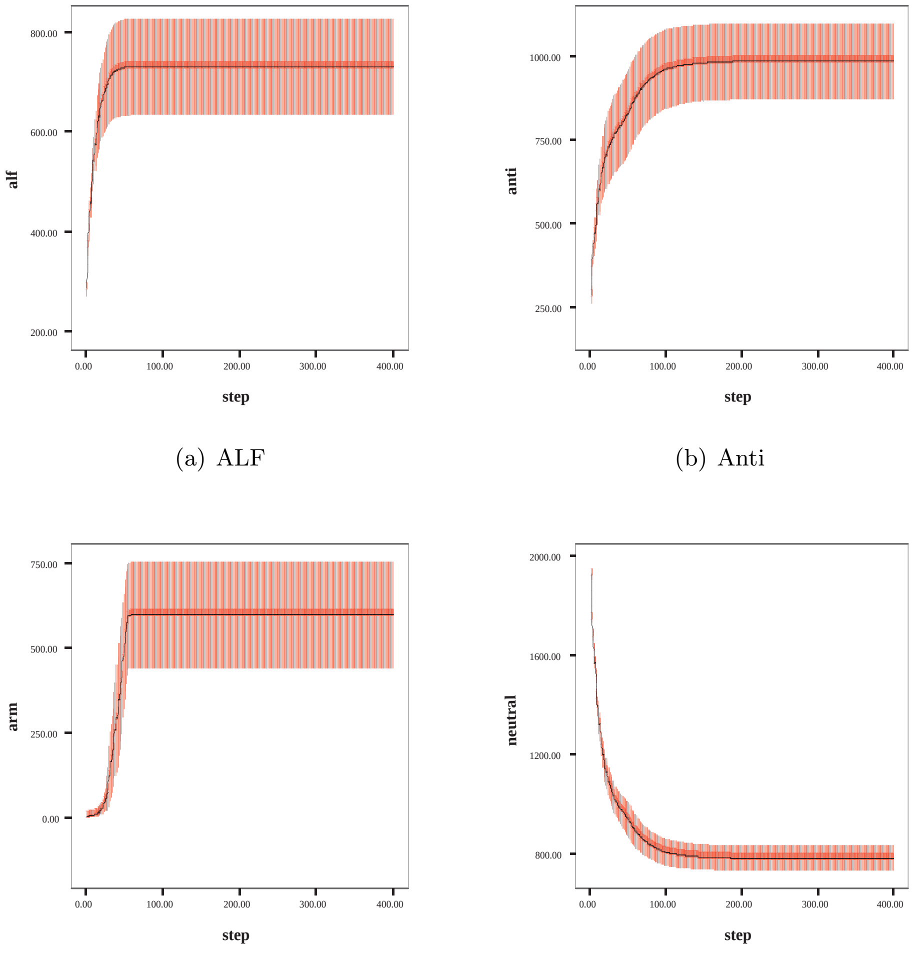


Figure 3.8: C1 overlaid plot. ALF, Neutral and Anti populations are of a similar size, which is shown by the overlapping lines for each. ARM numbers remain low.



(a) ALF

(b) Anti

(c) ARM

(d) Neutral

Figure 3.9: Experiment C2. Agents do not ignore other cultures, there is no mass media, and ARM group size is not restricted.

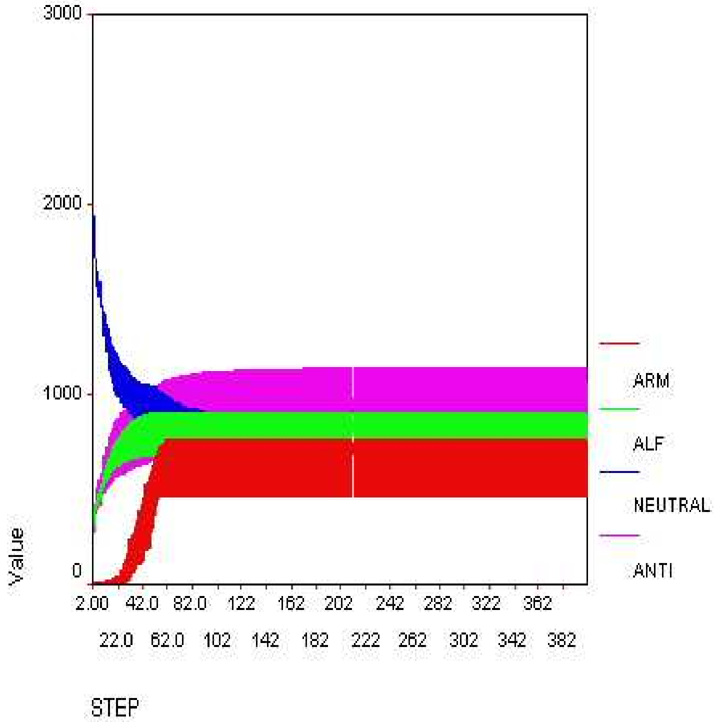
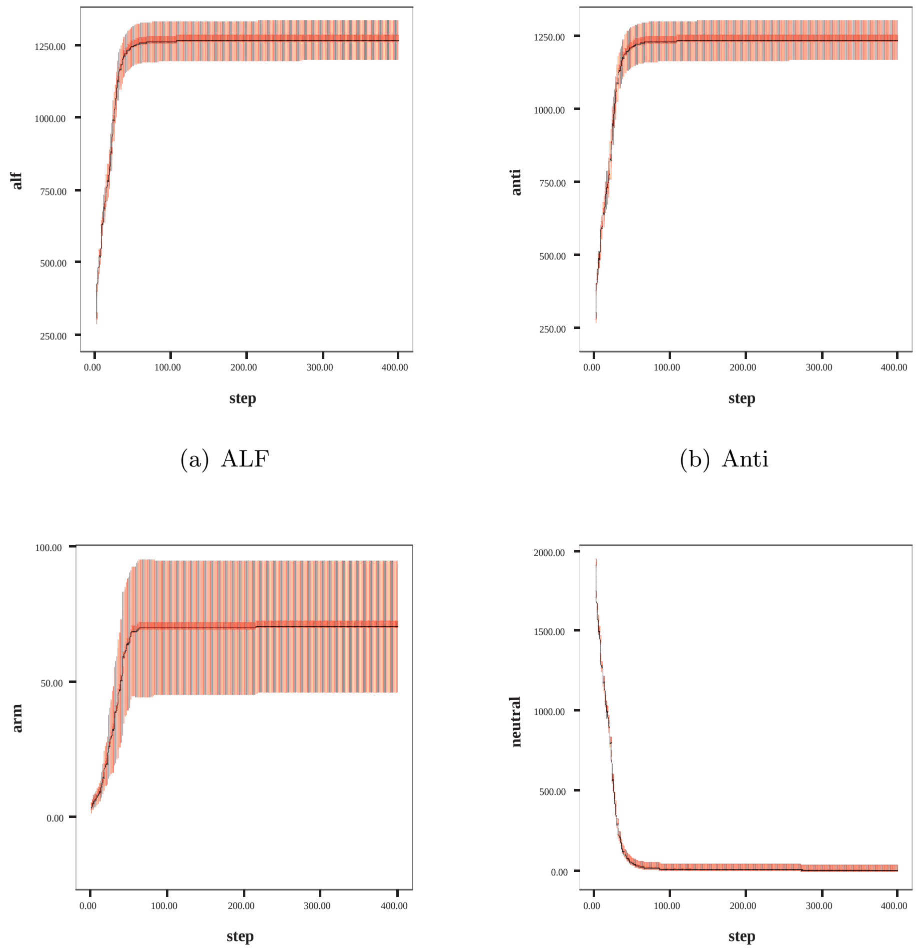


Figure 3.10: C2 overlaid plot. As with C1, but with the ARM group size restrictions lifted, ARM numbers nearly equal those of ALF, Neutral and Anti. This means that nearly all ALF agents has become ARM.

3.1.7 D1: Restrict Group Size

The D class experiments extend C1 and C2 by enabling the mass media mechanism, and we begin here with the default group ARM group size restrictions left intact.

Experiment D1 demonstrates complete polarisation of the agent population. Clustering is evident at an early stage, but whereas in experiments C1 and C2 the clustering stagnated, it is seen here to continue until no neutral agents remain. This is a noticeably swift process too, with almost complete polarisation after approximately 75 steps. ARM clusters are also emergent from the ALF clusters.



(a) ALF (b) Anti

(c) ARM (d) Neutral

Figure 3.11: Experiment D1. Agents do not ignore other cultures, mass media is used, and ARM group size is restricted to five members.

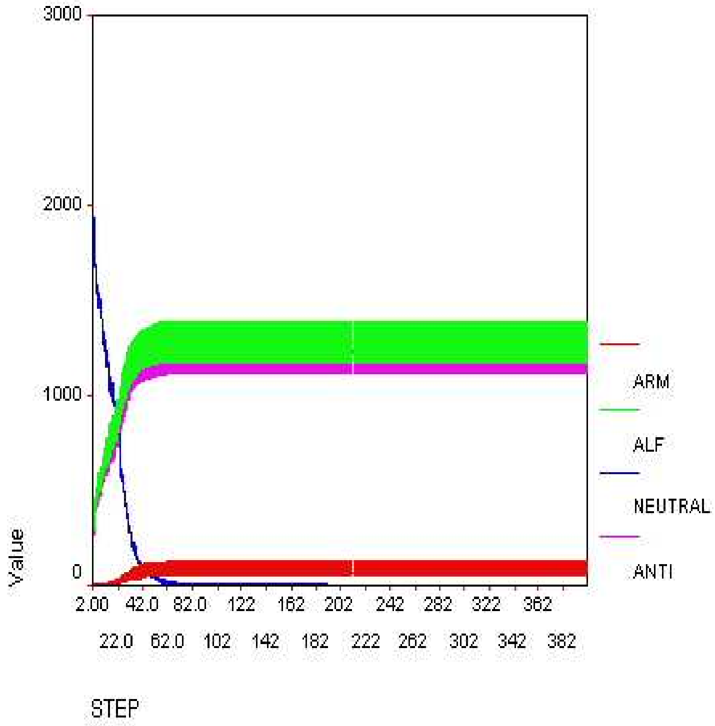


Figure 3.12: D1 overlaid plot. The ALF and Anti agents share the total population almost equally, with complete polarisation demonstrated by the Neutral line reaching zero on the vertical axis.

3.1.8 D2: No Size Restrictions

As we have seen in the other experiments, lifting restrictions on ARM group size makes no perceptible change to the model's overall behaviour. However, it has a significant impact on the number of ARM agents. In this case, we actually find that very few—if any—of the ALF agents avoid being recruited as ARM.

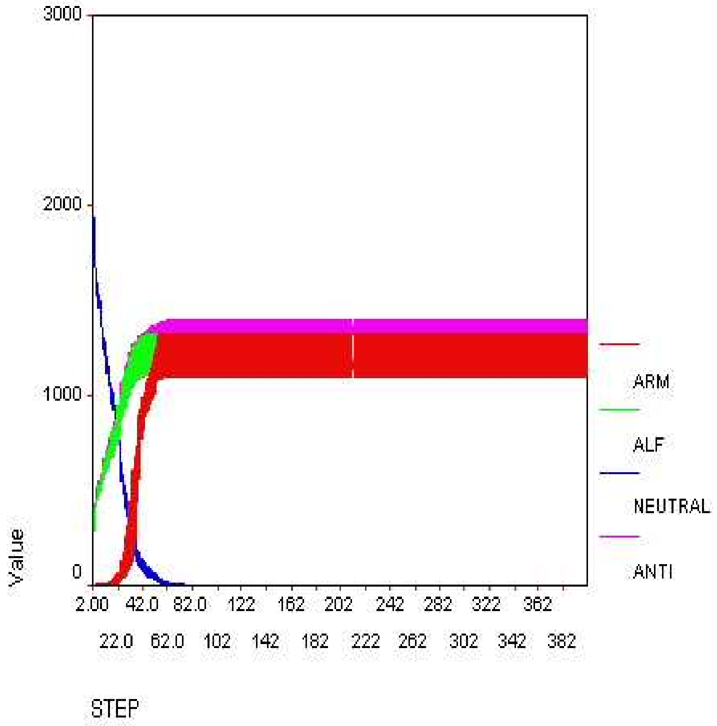


Figure 3.13: D2 overlaid plot. As with that of experiment D1 in Figure 3.12, but the ARM contingent has achieved total recruitment of ALF agents.

3.2 Results of Secondary Experimentation

The secondary experiments are in fact primary experiments C1, C2, D1 and D2 but with the respawn mechanism in opperation. These experiments were chosen—where pairs A and B were ommited—because of the interesting results that they yielded. One does not agree with spending time extending what are already rather unexciting simulations.

This set of experiments are documented in reverse–pair order because of the relationships between them. These are such that it seems sensible, in hindsight, to present them to the reader in this way. The associated analysis may be found in Section 4.3.

3.2.1 Experiment D with Respawn, Size 5 (DR5)

This experiment illustrated to oneself the importance of running a simulation for a duration long enough as to allow it to stagnate. After an initial phase of rapid polarisation, the model apparently settled, with ALF and Pro–Test agents maintaining a population share of roughly equal proportions. The ARM contingent meanwhile, rather gradually grew in size, apparently innocuously. Not until after some 600 steps was a significant change to manifest itself. At this point, the model changed completely, with the ALF and ARM population plummeting in unison, whilst the Pro–Test population reacted oppositely, *growing* at the same rate. This trend continued until stabilising, with Pro–Test agents gaining almost complete consensus.

Figure 3.14 is not plotted with the full complement of data that was recorded. The operational restrictions imposed by the SPSS statistics package meant that the volume of data gathered could not be plotted directly. If seeking assurances that this graph is not misrepresentative, the reader is directed to Figure A.6 in Appendix A.2. The plot there is constructed from a random thirteen percent sample of the recorded data–thirteen percent being the largest percentage sample that could be taken whilst remaining manageable by SPSS. This sampled plot clearly shows a very similar formation to 3.14.

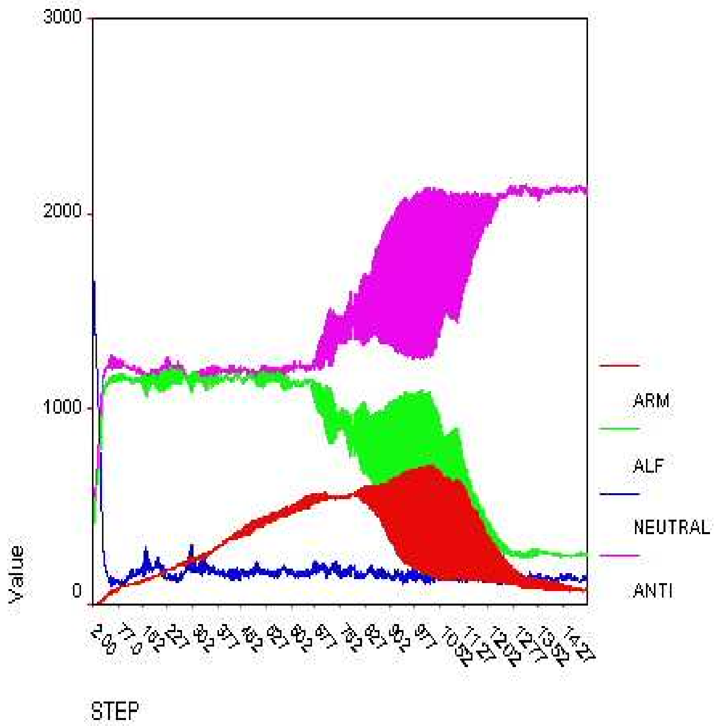


Figure 3.14: DR Size = 5. An overlaid plot showing the simulation run without agents ignoring other cultures, with mass media used, respawn active, and ARM group size restricted to five members.

3.2.2 Experiment D with Respawn, Unlimited Size (DRU)

With no restrictions on group size the simulation behaves in a similar—although greatly accelerated—fashion as Experiment DR5. The initial period of rapid polarisation also sees the ARM contingent recruit nearly all of the ALF agents. When polarisation is complete however, the ALF and ARM population suddenly reduces just as in Experiment DR5. This trend is reflected—as before—in the Pro–Test population, which continues to grow until once again, each culture's population share stabalises.

Notice here, that all meaningful simulation data could be collected within a period of 500 steps. The previous experiment (DR5) required the simulation to be run for a duration of 1500 steps until one could be confident that no further significant change would occur.

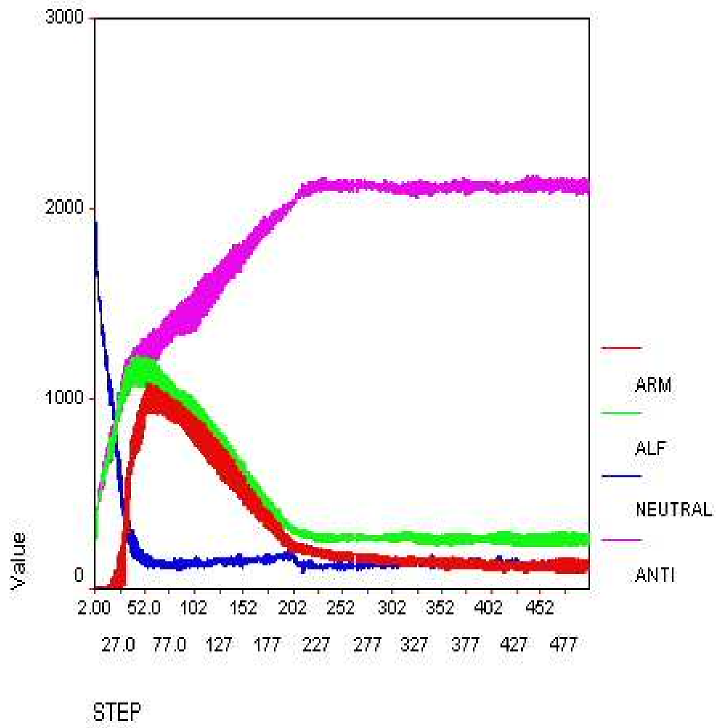


Figure 3.15: DR Size = unlimited. As with Figure 3.14, but no restrictions on the size of ARM groups. Also plotted over just 500 steps, rather than the 1500 used in the previous figure.

3.2.3 Experiment C with Respawn, Size 5 (CR5)

Experiment CR5 behaves in much the same way as DR5, with two exceptions. Firstly, there is not the initial polarisation, as in the DR pair; the neutral population does decrease, but much more gradually. Secondly, ARM agents are less prevalent. This is a pattern that is also evident in the next experiment, CRU.

Similarly to Experiment DR5, the run time needed to properly understand the simulation needed to be increased from the usual 400 steps. This time, a period of

800 steps was sufficient.

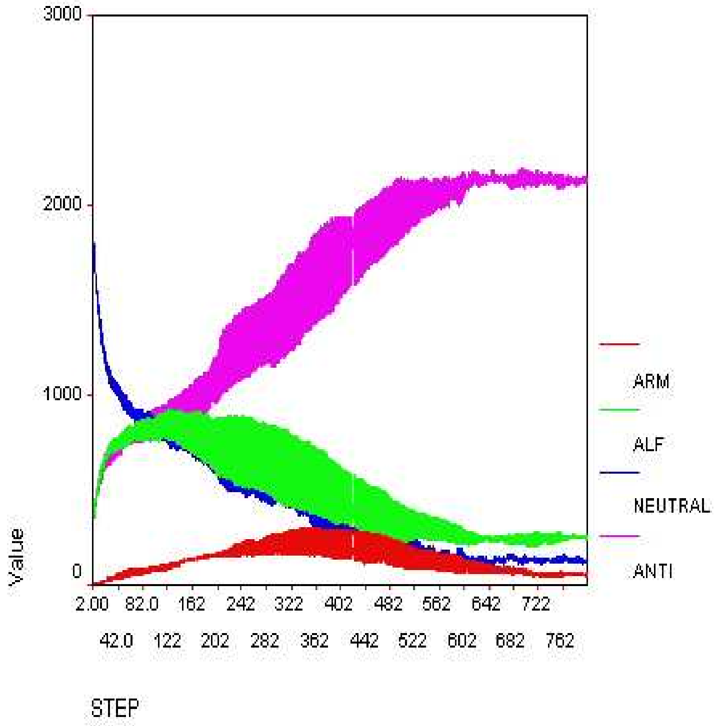


Figure 3.16: CR Size = 5. An overlaid plot show the simulation run without agents ignoring each other, no mass media, respawn active, and ARM group size restricted to five members. The simulation was required to run for 800 steps with these parameters.

3.2.4 Experiment C with Respawn, Unlimited Size (CRU)

As in related Experiment CR5, the two main ways in which this experiment differs from its counterpart (Experiment DRU) is in the absence of rapid polarisation, and the emergence of fewer ARM agents. The end result however, of Pro–Test gaining consensus, remains the same. Notice too, that a duration of just 500 steps was ample time for the simulation to stabalise.

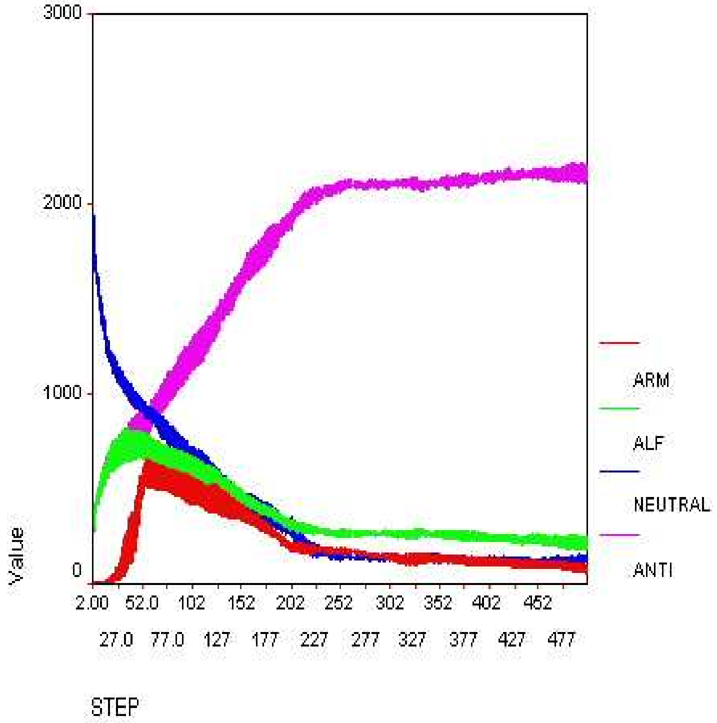


Figure 3.17: CR Size = unlimited. As with figure 3.16 but no restrictions on ARM group size. Although shown to have run for 500 steps, the usual 400 would have sufficed.

Chapter 4

Analysis of Results

Having summarised the results of our experiments, we may now explain how they came to manifest themselves, and consider how much support they lend to our hypotheses. Where appropriate, it will no doubt be prudent to contextualise behaviours with the application of associated research, and possibly speculate the significance of any findings.

4.1 Analysis of Primary Results

4.1.1 Experiments A1 and A2

This pair of experiments demonstrate the significance of cultural inter–communication. Neutral agents, that would otherwise assimilate their neighbours' cultural identity with their own, ignore all agents except for those neutral ones that exist in its vicinity. Because of this, there is no very little scope for transformation into AFL or Pro–Test agents. At the beginning of the simulation, some neutral agents do change culture, but this is only by exchanges with neighbouring neutrals, that just so happen to change the balance of 0s and 1s in the agents CIS and precipitate a cultural switch.

One would expect this scenario to result in a very closed society where those of similar culture bind together into clusters. That this does not happen here should not reduce our confidence in the model though. It is important to remember that the Cultural Identity String represents one rather small facet of a person's cultural make–up; their opinion on Animal Testing. In this situation, the agents simply do not communicate their opinion, and so it remains latent.

That these opinions are not a socially 'hot topic' does nothing to help the creation of ARM groups either. Activist agents are still able to recruit, which they do successfully, but the overall lack of ALF agents reduces the probability that an ARM agent will be close to a recruitable ALF agent. If few people have formed a strong opinion of a cause, then one will likely be hard–pressed to find numerous recruits.

Even the restriction on group size are removed in A2, generally less than half of the ALF population are recruited into ARM groups. Recall that restrictions on group size are largely a measure designed to maintain high levels of secrecy in order to avoid the law and flout counter–terrorist actions. It follows then, that complete removal of restrictions represents a situation where ARM activists enjoy—or at least perceive—total impunity, or are extremely skilled in the art of secrecy. Even in this extreme social climate, activist agents fail to dominate.

In Section 2.1.3 it was hypothesised that ARM groups in the simulation would "have such limited potential for growth, that restrictions upon their size are arbitrary". One could argue that this is supported, but only to an extent. It does indeed seem that, with in these experiments, the proliferation of activist agents is difficult. Even with size restrictions removed, only perhaps half of ALF agents turn activist. However, the number of activists in this case, compared to when the restrictions remain in place, are very significant.

4.1.2 Experiments B1 and B2

These two experiments depict a situation that is very odd indeed. Although the neutral agents do not interact with non–neutral agents (as in A1 and A2), they are influenced by biased media sources. These sources vary for each agent, but consist of one CIS containing mostly 0s, and another mostly 1s. The proportions of ALF and Pro–Test agents increase at similar rates until 20 steps. At this point, the 'terror gradient' is assessed. If the terror gradient is large, (greater than 1) then media influence is guaranteed. Further to this, neutral agents eliminate several of their neighbours from cultural tag comparisons. With fewer neighbours to moderate opinions, the media source that is used becomes rather more significant.

For example, consider an agent with eight neighbours, all either Pro–Test, neutral, or ALF agents. The influence of mass media is equivalent to the addition of another (biased) neighbour. If every neighbour is included in CIS tag comparisons, then the media source only comprises $1/9^{th}$ of the influence. Say though, that six of this agent's neighbours are culturally different, and therefore excluded from the tag comparison process. Given that there are now only two real neighbours with which the agent communicates, the mass media source now has an influence of $1/3^{rd}$. Whilst it must be remembered that these exact proportions are an artefact of simulation, the relationships between them when viewed as a *process* should generalise.

This pair of experiments does not seem to support our hypotheses to any meaningful extent, but perhaps this is to be expected. Polarised mass media does not ordinarily exist without topical debate, and so it should not be too surprising that the simulation of such an environment yields unexpected results.

4.1.3 Experiments C1 and C2

As noted in the results, experiments C1 and C2 provide an excellent example of clustering—an emergent property that is typical of social simulations. As neutral agents engage in social exchange with non–neutral agents as well as culturally similar ones, cultural identity is able to spread throughout the population. Areas dominated by majority CISs manifest themselves as ARM or Pro–Test clusters. There also remains a good proportion of neutral agents, and although the number of ARM agents remains small, it is marginally higher than that achieved in experiments A1 and B1.

This result is one that perhaps the reader is most able to envisage, as it is 'feels' natural. Those agents who communicate with others that possess a strong bias may well be 'converted'. Also though, some agents remain neutral by not being exposed to a strong enough bias. This represents a situation where individuals are not required to form an opinion. In reality of course, it is possible that most people have not invested the time in forming a solid opinion of the animal rights debate. Indeed, a cynic may add that most people do not invest sufficient time in any issues that do not directly affect them.

The proliferation of ARM groups in C2 is particularly interesting. Lone activists usually emerge at a number of positions in the agent space, and for the first few steps steadily add to their group. When the terror gradient is assessed at step 20, effectively increasing the likelihood that an ALF member will be successfully recruited, what we witness is the beginning of an upsurge in ARM membership. When the terror gradient is recalculated at 40 steps, it is a significantly lower value. However, ARM growth continues at a similar rate. This is because a critical mass of ARM agents seems to have been reached, so that the recruitment trend is now self–enforcing. Before the terror gradient is next calculated, (at 60 steps) ARM rapidly reaches a plateau. At this point, no suitable ARM candidates are reachable from existing activists.

Such behaviour is clearly at odds with hypothesis H1 is Section 2.1.3. The removal of size restrictions in experiment C2 leads to a dramatic rise in the number of activist agents, an increase that sees the majority of ALF agents become activist.

4.1.4 Experiments D1 and D2

With the addition of mass media influence in D1 and D2, we observe similar clustering to that of pair C, but in the context of complete polarisation. At the beginning of the simulation, an agent has just a 10 percent chance of involving a biased media source in a cultural exchange. As the terror gradient increases however, this can rise to 100 percent, thus involving one of the two media sources in every cultural exchange. When the terror gradient becomes less acute, virtually every agent has become ALF or Pro–Test affiliated, and some small ARM clusters are seen to emerge. Any remaining 'neutral' agents eventually become absorbed into a biased group whether or not with the help of media influence.

This scenario could not be confidently related to a large and diverse population. It is unrealistic to imagine that media coverage of an issue such as animal rights ever escalates to such a degree that the whole of Great Britain, for example, is heavily biased toward one particular opinion. However, it is possible that this model can be applied to a smaller population. If one considers the city of Oxford for example, campaigning ALF supporters or individuals from similar organisations such as SPEAK[1] are a daily feature of the city center. Countering this publicity is the group Pro–Test, (as used throughout our research) who raise public awareness over the benefits of animal testing. In this reasonably small population, with existing media influence from both ends of opinion spectrum, one can imagine the possibility of most individuals forming a strong opinion of the issue. I believe that this would be especially true if a significant number of ARM attacks were performed, thus raising the terror gradient and increasing media coverage.

[1]SPEAK involve themselves in the animal rights debate through pro–active campaigning and can be found on–line at www.speakcampaigns.org.uk.

An opinion poll from ICM (2005) reports that a randomly selected group of 1000 adults were very much divided over the question "Do you agree or disagree with the use of animals in experiments to test new medicines?". 50 percent said yes, 47 percent answered no, and 3 percent said they did not know. When pressed for an answer it seems, most people are able to respond and, interestingly, this particular issue seems to divide the two groups equally (as demonstrated in experiments D1 and D2.

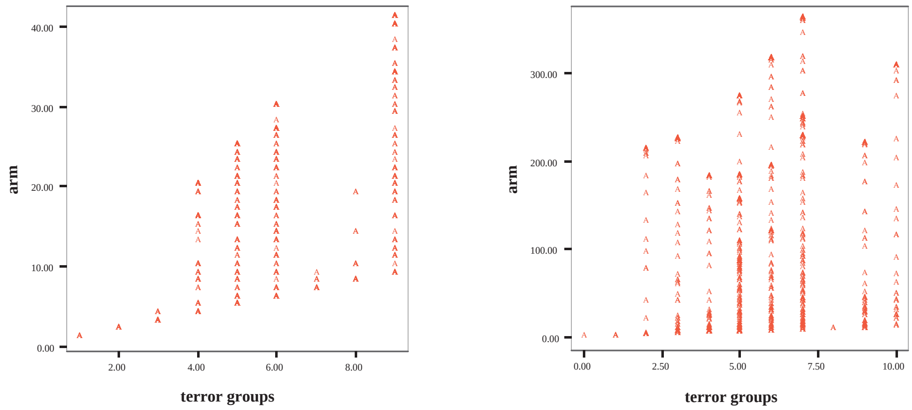
Perhaps one could go as for as to suggest that a strong media presence encourages individuals to make a choice, just as a direct question may. However, the media does influence our model in this way if inter–agent communication is reduced. The results of experiments B1 and B2 are very different, with Pro–Test agents far out–numbering ALF agents. It seems that balanced polarisation does not result when the media opperates in isolation. Mass media of course, never exists in a vacuum. In essence, its very being is dependent upon the prevalence of topical debate (debate of course, implying the communication between individuals of different opinions), and this is something that is demonstrated in these experiments.

4.2 The Significance of Restriction

It was hypothesised in Section 2.1.3 that the growth of ARM groups would be so difficult, that imposing an upper size limit of five members (as suggested in ALF literature, BiteBack (2005)), was an arbitrary measure. We have seen however, that the experimental results strongly suggest otherwise. The following figures show plots illustrate this. The reader will notice how figures 4.1 to 4.4 depict in their left–hand graph, a linear correlation between the number of terror (ARM) groups, and total number of ARM agents. This correlation may be observed most acutely in Figure 4.4(a), where most the most ARM agents are in existence. Such linearity leads one to believe that, since ARM groups are consistently reaching maximum membership, they are also constantly striving to increase membership, but being suppressed by the group size restriction. Indeed, the accompanying plots–figures 4.1 to 4.4 (b)–complete the picture.

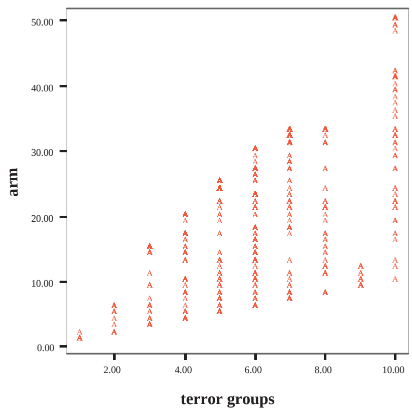
Lifting the restrictions results in an increase in the total number of terror groups, but this is marginal. The real interest lies in the elimination of linear correlation as observed in the restricted graph set. The number of ARM members is much more significant, much earlier on in the simulation. With unbounded potential for growth (within the constraints of the environment), we see that ARM groups recruit many more ALF agents than before. For example, with the size restriction left at the default of 5, a simulation with currently 9 ARM groups is limited to 45 ARM members. Figure 4.4(b) though, clearly shows that when 9 ARM groups were operating, there some simulations amassed over 1200 members.

It seems to be that the self–imposed group size limits may serve a dual purpose. They appear primarily to be a means of preserving the secret identity of the activist groups themselves, but also have the effect of limiting the extent to which activism becomes prevalent within the ALF community. Conspiracy theorists may like indulge themselves by pondering over whether the writers of the "Animal Liberation Primer" (Anonymous, 2005) also considered this duality (and if so, then who are they?).

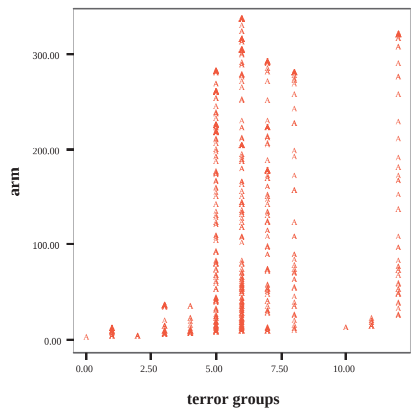


(a) Restricted (b) Unrestricted

Figure 4.1: Plot of ARM population against the number of terror groups for experiment pair A1 and A2

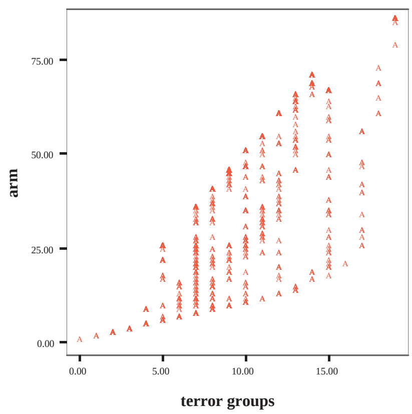


(a) Restricted

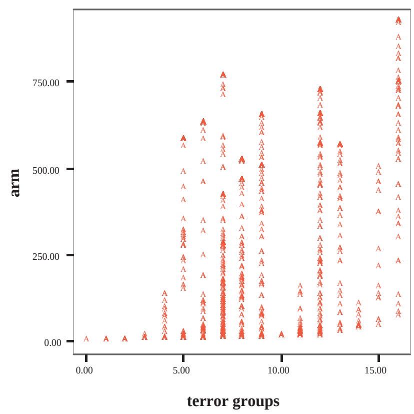


(b) Unrestricted

Figure 4.2: Plot of ARM population against the number of terror groups for experiment pair B1 and B2

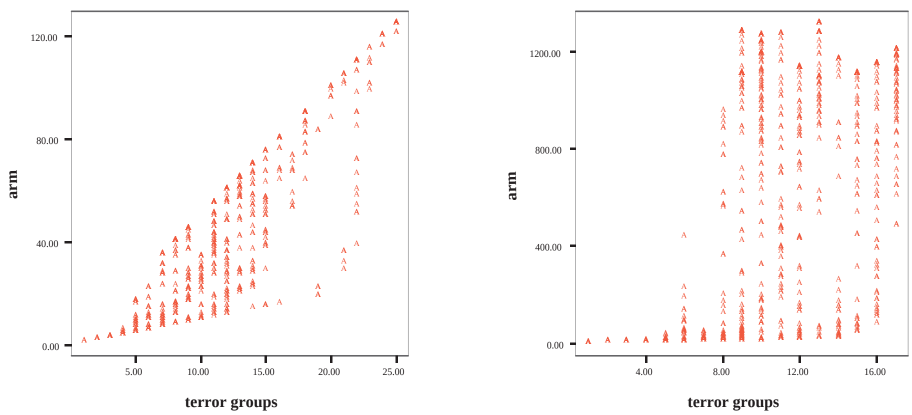


(a) Restricted



(b) Unrestricted

Figure 4.3: Plot of ARM population against the number of terror groups for experiment pair C1 and C2



(a) Restricted (b) Unrestricted

Figure 4.4: Plot of ARM population against the number of terror groups for experiment pair D1 and D2

4.3 Analysis of Secondary Results

The areas of primary experimentation, A1 through to D2, provided some interesting results, albeit in a limited context. The addition the 'respawn' mechanism however, leads to some much more interesting behaviour. In analysis of the primary results, we noted the tendancy of mass media influence to encourage polarisation of the agent population. This can also be observed in the secondary results. Since this matter has been attended to previously, let us turn our attention toward the exciting and unexpected phenomenon of a self–annhilating ALF.

What we witness is the initial growth of both ALF and Pro–Test groups. This may also be accompanied—in the case of unrestricted group size—by a proportional increase in ARM activity or, as we see with low–value restrictions, a steady increase in ARM numbers. In either situation, and for other restriction values in between these two extremes, there is a clearly observable phenomenon; after the initial growths, the Pro–Test group continues to grow in size, whilst ALF membership takes a down–turn. This reduction in ALF members is closely related to ARM membership and, in fact, is easily explainable by the stipulations that we have made with respect to the transfer of cultural identity.

For reasons discussed previously in Section 2.4.3, ARM activists are omitted from the cultural view of other agents. A 'neutral' agent, when assimilating its neighbours' culture, will not involve an ARM activist, but *will* involve an ALF member. If there is a situation where the ARM population has increased to a majority of the ALF population, then an agent involved in cultural exchange will have mostly other neutral agents, and Pro–Test agents to engage with. This imbalance quickly leads to a simulation space dominated by Pro–Test agents. The proliferation of ARM activists have effectively led to the annhiliation of the entire ALF movement.

Having already seen the importance of size restrictions, there is an obvious link here between ARM group size and this eventual imbalance. The ALF population actually becomes more sustainable the greater the restrictions on ARM group size. Far from aiding the growth of the ALF, the presence of ARM agents causes a decline by increasing the probability of media attention, but concurrently removing culturally influential ALF members (that have now turned to activism). In the TerrorPlex simulation, the ALF population is only able to compete with Pro–Test if the number of activist agents is kept low. Even with ARM group size restricted to just two members though, the total number of activist agents grows steadily until the trend is no longer sustainable. As before, the self–reinforcing imbalance emerges and polarisation by Pro–Test agents is imminent.

This is a situation of which similar examples in history may be found. Far removed from the animal rights debate, I believe similarities exist in the British 1979 election. The two largest parties of the time were Labour (regard as the ALF in the model) and the Conservatives (regard as Pro–Test), and shared a roughly equal proportion of votes. Labour however, had become closely linked with increasingly militant Trade Unions (equated to the ARM) who were becoming unpopular with the electorate. This unpopular relationship was been cited as one of the main reasons why Labour suffered a significant defeat to the Conservatives, and is probably why Labour went on to become a party not so influenced by the Unions.

Another comparison could be made to 1960's South Africa. The African National Congress were campaigning for full political rights, and opposing the all–white government of the time; the National Party. Under the influence of the more revolutionary South African Communist Party, the ANC prepared "a nationwide campaign of resistance"(Ellis and Sechaba, 1992). This planned resistance lead to the Sharpesville Masacre of March 1960, and caused the ANC to be banned by government[2]. Made illegal for the next 30 years, the ANC was forced underground.

Although the above two historical comparisons are very much different to the specific groups that our model simulates, there is a fundamental equivalence:

1. All situations involve opposing groups, consisting of members which are culturally similar within the group, but are very different *between* groups.
2. These groups are, or have the potential to be, reasonably equal in size or strength.
3. At least one group has members who share the group's core ideologies, but believe that more extreme measures are required to effect a desired change.
4. The extremist factions are able to grow.
5. This growth eventually becomes damaging to both the extremists and their parent group, allowing the rival group to strengthen.

Note that number 5 of the above list has yet to be seen—outside of the TerrorPlex model—within the context of animal rights. This behaviour though, was what we have been attempting to predict.

Much more research is necessary to validate the self–harming behaviour of the model discussed in this section. The initial results however, are most encouraging, and suggest potential for real insights into the behaviour of similar groups.

[2]It was not in fact the ANC that instigated the Sharpesville Masacre, but the racially–motivated Pan Africanist Congress who had broken away from the ANC and sought to upstage the ANC by demonstrating a week before the nationwide campaign was due to begin.

Chapter 5

Conclusions

This chapter is divided into three concluding sections. We begin by summarising the project as presented in this document, and its contribution to the field. Then a critique is presented in line with the requirements of prominent figure in the Agent–Based Modelling community. Finally, consideration is given to proposed improvements that the model could undergo, and associated areas of research that should be of potential interest.

5.1 Summary

This document began by drawing attention to the increasing need to better understand the organisational nature of modern terrorist networks. The Animal Liberation Front was identified as a culturally distinguishable group from which terrorist individuals emerge, forming the Animal Rights Militia. It is these groups that constitute the primary focus throughout this dissertation.

Having gained an insight into the mechanics of forming an extremist group, Agent–Based Modelling was identified as a reasonable research approach. This lead to the development of the 'TerrorPlex' model, designed to simulate the formation of these terrorist/activist groups upon a simple lattice structure. The simulation took into consideration several factors, including the influence of mass media. There was a definite move away from the physicalities of activist groups existing within a population. The literature survey had touched upon issues such as swarming (when considering the dynamics of protests) but the definition of a metaphysical agent space reflected a change in emphasis.

The execution of several high–confidence experiments provided a substantial data set. This data was then analysed, and some interesting phenomena were explained. We saw the polarising effect of media influence, the dual–function of ARM group size restrictions, and the self–destructiveness of an ALF population that allows itself to propogate a sizeable number of activist agents.

Much has been learnt throughout the course of this research project, and this is clearly reflected in the dissertation document. Knowledge has been gleaned from a large collection of sources, and proved vital in the advancement of thought, and ratification of implementation decisions.

Aside from being something of a personal achievement, this dissertation has been a success in terms of:

- Extending aspects of previous research (for example, (Mckeown and Sheehy, 2006, media effects) and [the likelihood of terror]taylor, taylor2).
- Formulating a model that, with further study, could potentially generalise to provide deeper insight to the social phenomena of extremist groups.
- Demonstrating the usefulness of using agent–based modelling techniques over within the social sciences.

Further to the primary objective of supporting the project, the arguments and citations presented in this document should be of much use to a reader who is embarking upon similar research. It is in fact hoped, that this document may provide the impetous for similar work, if not an extension of that presented herein.

5.2 Axelrod Decides

In his 2003 paper entitled "Advancing the Art of Simulation in the Social Sciences", Axelrod suggests that the programming of a simulation model should achieve three goals:

1. Validity—this is the 'internal validity' of a model as opposed to its 'real world' validity, as discussed earlier.
2. Usability—the extent to which a researcher is able to run and interpret the simulation, and to understand the internal structure and functionality.
3. Extendability—the simulation is of such sound construction and documentation as to allow a future researcher to adapt the program for further experiment.

The following sections address each of these three key points in turn.

Validity

A simulation in this sense is valid if it faithfully represents the proposed model. Internal validity appears to be high, although to support this wholeheartedly would require the administration of usual testing methodologies such as black and white–box testing.

Usability

Usability is apparent in three guises. Firstly, the user is able to readily manipulate several model parameters, providing large experimental scope. Secondly, real–time graphical output is required in the form of an environment display and associated sequence graph. Lastly, data is recorded for individual or batch runs in comma–delimited text files, that may be imported by any good statistical software package.

Extendability

Convention has been followed in terms of program separation (into the logical three classes), sensible use and re–use of methods, and ample commentary within the dissertation and the program code. Any interested person should find the TerrorPlex simulation easily extendible.

5.3 Future Research

If one is mindful of the challenge of completeness, as discussed in Section 2.2.1, it may well be concluded that the opportunity for improvement is boundless. It is hoped however, that the reader does not believe this to be the case, and will instead acknowlege but a few of the most interesting areas that I have identified as warranting exploration.

Media Effects

The inclusion of media effects in the TerrorPlex model was intentionally basic, but one feels certain that a more informed implementation could yield interesting results.

Agent Scope

In the current model, each agent has the same scope for interaction. That is, the 'Range' parameter—used for by the von Neuman and Moore neighbourhood methods—is shared by each agent. Although a varied population density results in agents having different numbers of neighbours, the variance is probably not altogether representative of reality.

If we contrive to make the range vary from agent to agent, then the simulation dynamic could change significantly. For example, an ALF agent with a social range of 1 could potentially be very isolated as—using the Moore neighbourhood method—it may have a maximum of just 8 neighbours. Consider also an activist agent beyond the scope of this ALF agent, but with a range of its own large enough to encompass the ALF agent. With this dynamic, one could enable a situation where the activist agent spots the isolated ALF agent and eventually recruits it into an ARM group.

Cultural Strength

The TerrorPlex model eliminates activist agents from a neutral agent's cultural scope, as we consider the activist agents to be publicly uninvolved in such exchanges in the interest of secrecy.

However, we a large proportion of the population are activist, perhaps it should be that they are included, at least to an extent. The existence of many activists within a population may suggest that they need not maintain such anonymity. If this is the case, perhaps activist agents in our model could influence neutral agents to becoming ALF, or even attempt to recruit agents directly from neutral groups.

An example of a similar thought may be found in the paper from Axtell and Chakravarty (2001) whose model 'lower class' activists to encourage the 'upper class' to play a particular strategy when encountering a lower class agent.

Terror Gradient

The terror gradient, though necessary, is unrealistic. It somewhat exaggerates the chance of ALF agents being recruited as ARM, and implies that all people perceive changes in ARM activity at exactly the same time. The calculation of the terror gradient could therefore be revised, and its influence staggered over a given time period.

Mutliple Affiliations

The TerrorPlex model developed in the course of this dissertation allows an activist agent to belong to just one activist group at a time. The case for multiple group memberships should be explored, initially for likelihood, and then possibly for impact.

Abstract Agents

The concept of 'abstract agents' was identified as a possible future development at the end of Section 2.4.7 having studied the work of (Berry et al., 2004). To progress in this direction however would require fundamental changes to the simulation.

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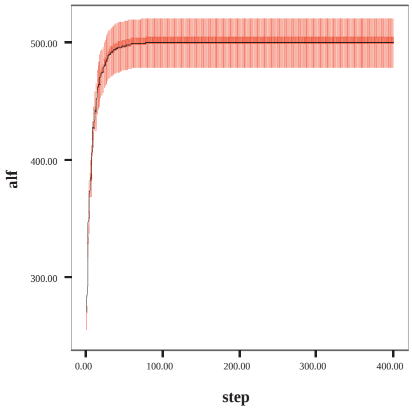
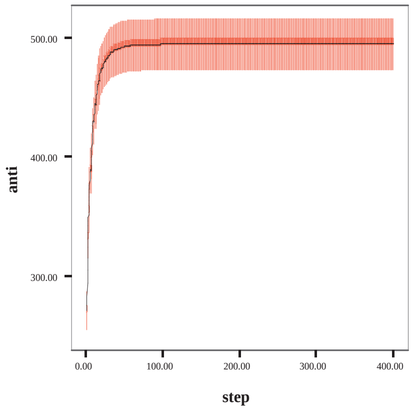
Appendix A

Supporting Plots

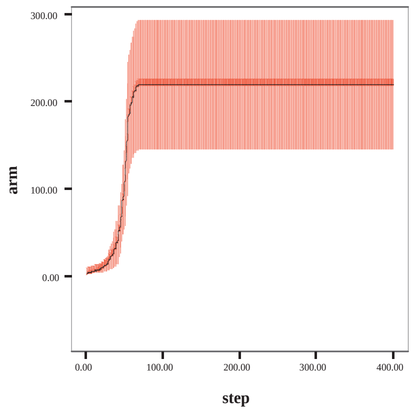
A.1 Primary Experimentation



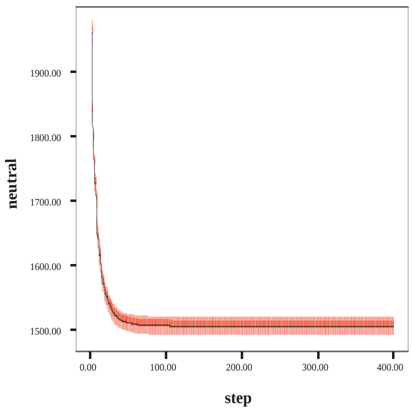
(a) ALF



(b) Anti

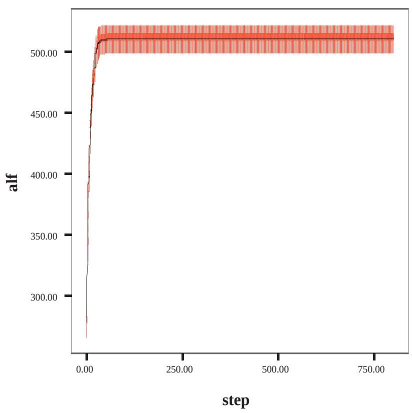


(c) ARM

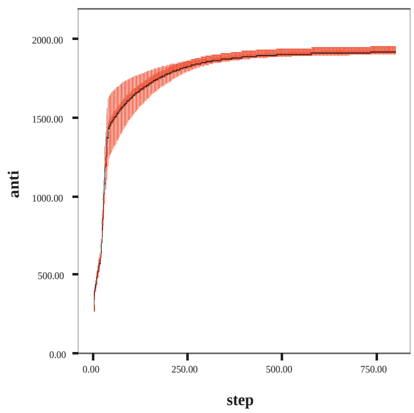


(d) Neutral

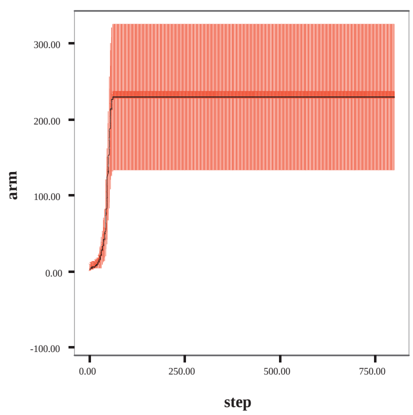
Figure A.1: A2: IOC no MM, unrestricted



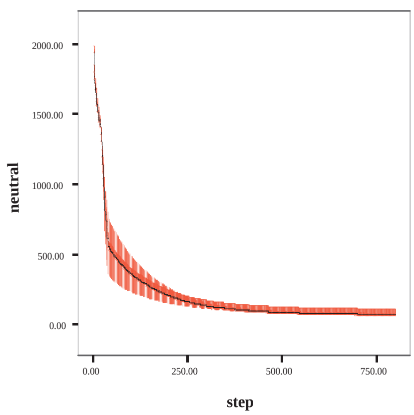
(a) ALF



(b) Anti

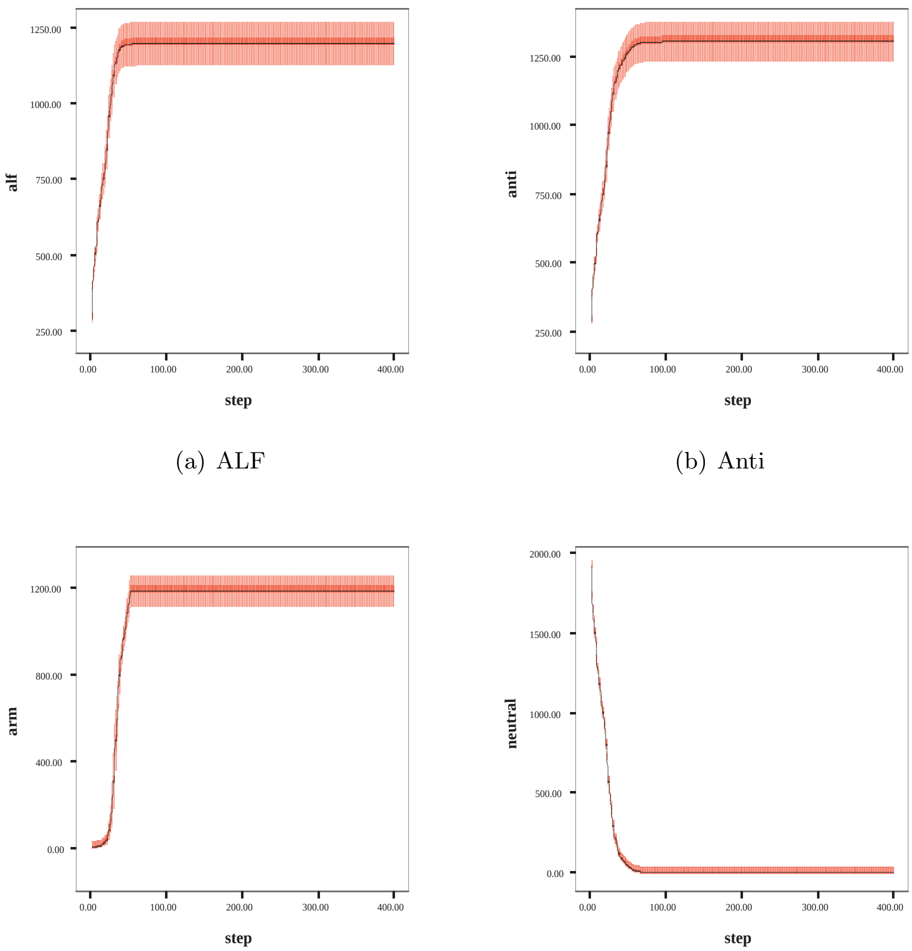


(c) ARM



(d) Neutral

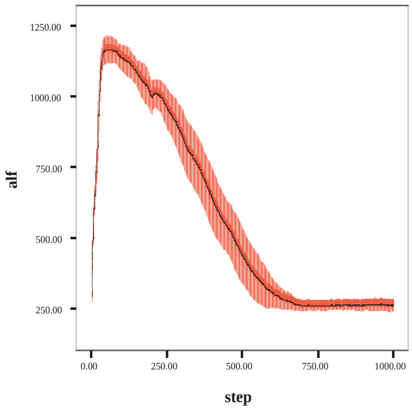
Figure A.2: B2: IOC with MM, unrestricted



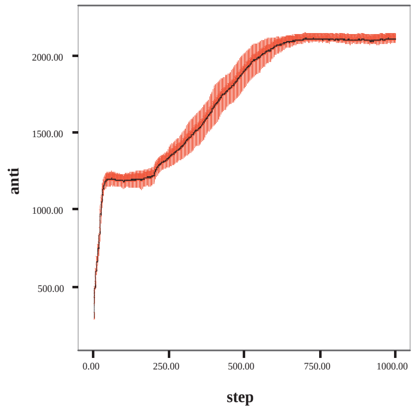
(a) ALF (b) Anti

(c) ARM (d) Neutral

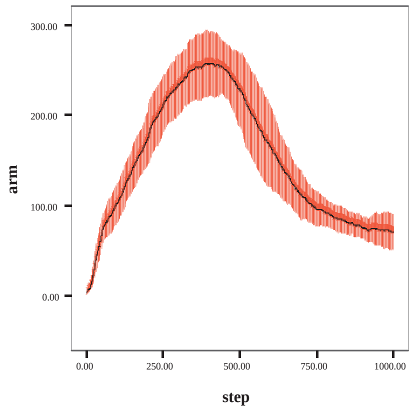
Figure A.3: D2: Do not IOC, with MM, unrestricted



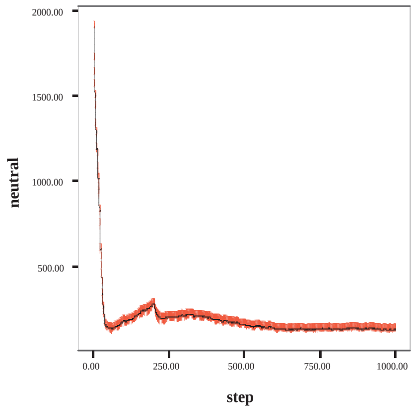
(a) ALF



(b) Anti

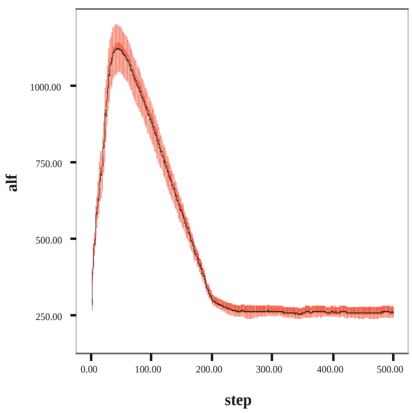


(c) ARM

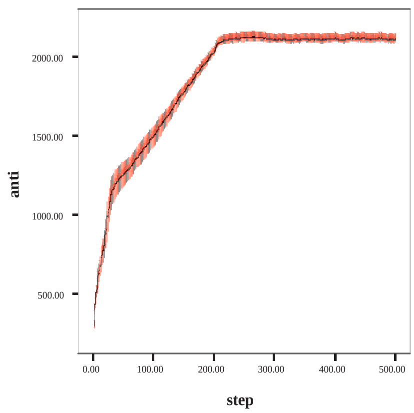


(d) Neutral

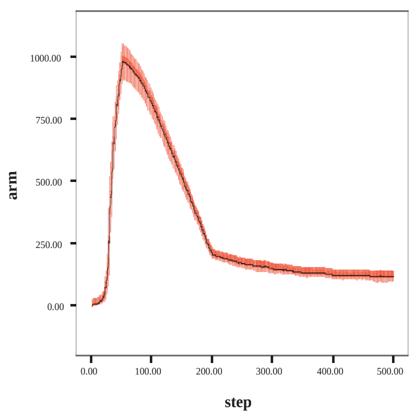
Figure A.4: DR5



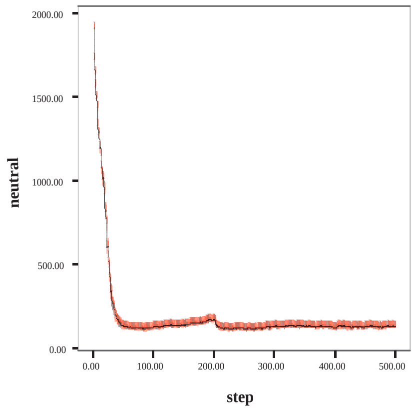
(a) ALF



(b) Anti



(c) ARM



(d) Neutral

Figure A.5: DRU

A.2 Secondary Experimentation

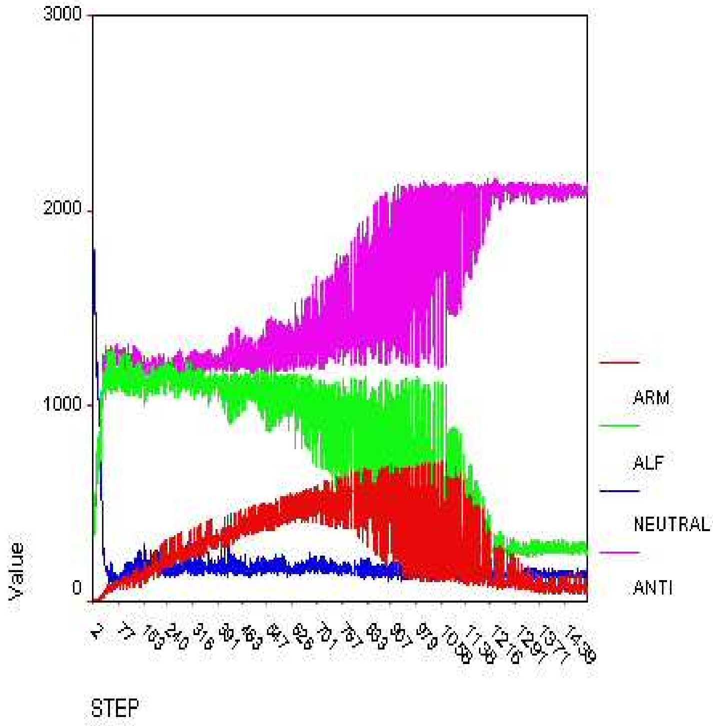


Figure A.6: DR Size = 5, all: 13 percent random data sample.

Appendix B

Code Listing

The program is divided into three classes, in accordance with agent–based modelling convention. These are:

1. TerrorPlexModel.java - which is largely responsible for the flow control and scheduling of the simulation plus ancillary functions such as data recording and output displays.
2. TerrorPlexAgent.java - this class governs the internal agent behaviour, maintaining or changing state and performing any agent functions identified as relevant in the dissertation.
3. TerrorPlexSpace.java - a small but important class which provides detail of the agent space (currently a Torus object projected onto a grid structure) and provides functions for managing the insertion or deletion of agents from the agent space.

When run within the Repast framework, no further code is required.

```
/*
 * Class: TerrorPlexModel ---> extends SimModelImpl
 *
 * This class is the basic model for the TerrorPlex simulation.
 * It is responsible for the core functionality, that includes
 * instantiating the agent space, filling that space with agents,
 * scheduling the simulation's actions, and recording data.
 *
 * This project was initially developed extending SimpleModel. This
 * proved restricting after some time though, and the classes were
 * re-coded to extend the more feature-laden SimModelImpl class. I
 * thank John T. Murphy from the University of Arizona & Arizona State
 * University, whose excellent online Repast tutorial proved invaluable
 * during this process.
 */

package demo;

import java.util.ArrayList; //Agent list
import java.util.Hashtable; //Combo box
import java.lang.Integer; //Combo box

import uchicago.src.sim.engine.BasicAction; //Scheduled actions
import uchicago.src.sim.engine.SimModelImpl; //Model base class
import uchicago.src.sim.engine.Schedule; //Scheduling
import uchicago.src.sim.engine.SimInit; //Initialisation
import uchicago.src.sim.gui.DisplaySurface; //Display
import uchicago.src.sim.gui.Object2DDisplay; //Display
import uchicago.src.sim.util.SimUtilities; //Shuffle method
import uchicago.src.reflector.ListPropertyDescriptor; //Combo box
import uchicago.src.sim.analysis.OpenSequenceGraph; //Plotting
import uchicago.src.sim.analysis.Sequence; //Plotting
import uchicago.src.sim.analysis.DataRecorder; //Recording to disk

public class TerrorPlexModel extends SimModelImpl {
  /*
   * The following is the set of simulation parameters, each of them
   * initialised with default values. All of these are alterable in the
   * Repast GUI, and the initial values reflect a personal choice devised
   * to provide swift demonstration of key features.
   */
  private int population = 2500; // The number of agents to be spawned
  /*The X and Y dimensions for our square agent space*/
  private int gridSize = 60;
  /*Restrict group size to this number. 0 indicates no restriction*/
  private static int Restrict = 5;
  /*Turns media influence on or off (true/false)*/
  private static boolean MassMedia = true;
  /*0 = Moore neighbourhood, 1 = von Neuman*/
  private static int NeighbourMethod = 0;
  /*The extent of neighbourhood evaluation in all directions*/
  private static int Range = 2;
  /*Agents ignore those of different cultures (true/false)*/
  private static boolean Ignore = false;
  /*Turns life and death on or off*/
  private static boolean Respawn = false;
  /*The number of steps for which the model should run*/
  private static int StepLimit = 400;

  /*The schedule object manages the simulation's actions*/
  private Schedule schedule;
  private DisplaySurface dsurf; // Our display surface
  private OpenSequenceGraph plot; // For generating real-time plots

  /*Each agent from the population will be stored in this list*/
  private ArrayList agentList;

  /*For data recording and plotting*/
  private int numARM, numALF, numNeutral, numAnti, tagFlips;

  /*Terror gradient initialisation, and basic Terror Gradient*/
  private static double terrorGradient = 0;
  private static double basicTG = 0.1;

  private static int lastGroupID = 0;
  private int currentGroupID;
  private int stepCount = 0;
  private boolean agentRespawn = false;

  /*For use in generating biased media sources*/
  private static double biasProbability = 0.7;
```

```
  /*Define our agent environment*/
  private TerrorPlexSpace tpSpace;

  /* The DataRecorder type enables the recording of simulation data
   * to disk.
   */
  private DataRecorder recorder;

  /* A hashtable is required for drop-down boxes. In this case for the
   * selection of neighbourhood method
   */
  Hashtable h1 = new Hashtable();

  /*The getName() method is mandatory.*/
  public String getName(){
    return "Terror Simulation";
  }

  /* The mandatory setup() method, as one would expect, prepares the
   * simulation upon each new run for example by setting variables,
   */
  public void setup(){

/* Reset values between runs for proper recording of simulation
 * data.
 */
numARM = numALF = numNeutral = numAnti = tagFlips = 1;

/* Teardown display surface if necessary, then create and register
 * a new display surface
 */
if (dsurf != null) dsurf.dispose();
   dsurf = new DisplaySurface(this, "Terror Sim");
   registerDisplaySurface("Terror Sim", dsurf);

/* Create and register new display surface onto which the agent
 * space is mapped
 */
    dsurf = new DisplaySurface(this, "Population Display");
    super.registerDisplaySurface("Population Display", dsurf);
```

```
 /*Teardown sequence plot is necessary*/
 if (plot != null) plot.dispose();

 /*Create new sequence plot, type OpenSequenceGraph and label axis*/
 plot = new OpenSequenceGraph("Terror Model", this);
 plot.setAxisTitles("Steps", "Number");

 /*Each line that is to be plotted needs to be defined*/
 plot.addSequence("ARM Contingent", new Sequence() {
   public double getSValue() { return numARM; }
 });
 plot.addSequence("ALF inc. ARM", new Sequence() {
   public double getSValue() { return numALF; }
 });
 plot.addSequence("Pro-Test", new Sequence() {
   public double getSValue() { return numAnti; }
 });
 plot.addSequence("Neutral", new Sequence() {
   public double getSValue() { return numNeutral; }
 });
 plot.addSequence("Tag Flips", new Sequence() {
   public double getSValue() { return tagFlips; }
 });

 /* Associate the Moore and von Neuman neighbourhood methods with
  * integer values, and embed them in the hashtable which is then
  * used in creating a List Property Descriptor and finally added
  * to the simulation's descriptor list.
  */
 h1.put(new Integer(0), "Moore");
 h1.put(new Integer(1), "VonNeuman");
 ListPropertyDescriptor pd =
  new ListPropertyDescriptor("NeighbourMethod", h1);
 descriptors.put("NeighbourMethod", pd);

 /*Create a new schedule*/
schedule = new Schedule(1);

/* Ensure the terrorplex agent space is null before beginning the
 * simulation.
 */
```

```
 tpSpace = null;

 /*Reset stepCount to zero. Step is synonymous with 'tick'*/
 stepCount = 0;
 /*Set terrorGradient to the default double variable, basicTG*/
 terrorGradient = basicTG;

 /* Reset lastGroupID and currentGroupID to zero. Required in
  * calculation of Terror Gradient
  */
 lastGroupID = 0;
 currentGroupID = 0;

 /*The agent population is stored in a list*/
 agentList = new ArrayList();
}

/* The begin() method really acts as a launch-pad for other required
 * methods
 */
public void begin(){
  buildModel();
  buildSchedule();
  buildDisplay();

  /*Display on screen our display surface*/
  dsurf.display();

  /* Set the starting value and range for the plot axes, then display
   * the plot area
   */
  plot.setXRange(0, 400);
  plot.setYRange(0, population);
  plot.display();
}

public void buildModel() {
/* Initially set to false, this is changed after one
 * simulation run
 */
agentRespawn = false;

/*Define where recorded data is to be stored and the field names*/
recorder = new DataRecorder("./data.txt", this,
 "Run Step Seed ARM ALF Neutral Anti Flips TGrps TGrad");

/*Add all desired data sources to the recorder object*/
recorder.createNumericDataSource("ARM", this, "getNumARM");
recorder.createNumericDataSource("ALF", this, "getNumALF");
recorder.createNumericDataSource("Neutral", this, "getNumNeutral");
recorder.createNumericDataSource("Anti", this, "getNumAnti");
recorder.createNumericDataSource("TagFlips", this, "getTagFlips");
recorder.createNumericDataSource("TerrorGroups", this,
 "getTerrorGroups");
recorder.createNumericDataSource("TerrorGradient", this,
"getTerrorGradient");

/* Make new square TerrorPlexSpace with dimensions x=gridSize
 * and y=gridSize
 */
tpSpace = new TerrorPlexSpace(gridSize, gridSize);

/* If the population is too large for the available space,
 * then an error message is output, and the simulation brought
 * to a halt.
 */
if(population > (gridSize * gridSize)) {
System.out.println("Error: Too many agents for grid space");
stop();
}

/*Add number of agents specified by the population variable*/
for(int i = 0; i < population; i++){ addAgent(); }

/* We need to know if adding new agents part-way through
 * a simulation
 */
agentRespawn = true;
}

public void buildSchedule(){
/* This internal class specifies an action that is to be carried
```

```
   *  out at each step of the simulation.
   */
  class TerrorPlexStep extends BasicAction {
      public void execute() {
     /*Reset any step-independent variables*/
   numARM = numALF = numNeutral = numAnti = 0;
   tagFlips = currentGroupID = 0;

   /* Increment step count, which is static and so persists
    * between steps
    */
   stepCount++;

   /* Re-arrange the agent list so that we do not deal with
    * agents one after another in the same order each step.
    */
        SimUtilities.shuffle(agentList);

        /* We iterate through each agent of the list and execute
         * the step() method which is passed any necessary program
         * variables.
         */
        for(int i = 0; i < agentList.size(); i++){
          TerrorPlexAgent subject = (TerrorPlexAgent)agentList.get(i);
          subject.step(NeighbourMethod, Range, Restrict, MassMedia,
            Ignore, terrorGradient, population);

          /* For recording purposes, relevant variables are
           * incremented as appropriate
           */
          if(subject.getisActive() == true) {
           numARM++;
           numALF++;
          }
          else if(subject.getisALF() == true) numALF++;
          else if(subject.getisAnti() == true) numAnti++;
          else numNeutral++;

          if(subject.getFlip() == true)
tagFlips++;
```

```
          /* Returns not the agent's group that it belongs to
           * (if any) but the current group ID of the model as
           * a whole.
           * */
          currentGroupID = subject.getLatestGroupID();
        }
        /* Comment out these two to avoid having to output
         * graph and grid when conducting batch runs
         */
  plot.step();
      dsurf.updateDisplay();

      /* If the simulation has been running for the number of
       * steps (manipulated through the user interface, then it
       * is stopped. Notice that if StepLimit is set to 0, then
       * the conditional will never be met and in theory the
       * simulation will run indefinately.
       */
      if((StepLimit != 0) && (StepLimit == stepCount))
       stop();

      /* If the respawn option has been checked, then we must
       * reap any agents whose lifetime has expired, and then
       * replenish the agent space with the same number of agents.
       */
      if(Respawn == true) {
       int deadAgents = reapDeadAgents();
       for(int i = 0; i < deadAgents; i++){
       addAgent();
       }
      }
    }
  }

/* Calculation of the TerrorGradient is performed as a BasicAction.
 * If the number of activist groups has increased from the last
 * time that the TerrorGradient was calculated, then it is
 * re-calculated.
 */
class TerrorGradient extends BasicAction {
    public void execute() {
```

```
        if(currentGroupID > lastGroupID) {
        /* Terror gradient is the difference in terror groups
         * from one period to the next
         * (currentGroupID - lastGroupID) multiplied by a
         * value slightly larger than the basic Terror
         * Gradient.
         */
        terrorGradient = (currentGroupID - lastGroupID) *
         (basicTG + 0.5);
        /* lastGroupID is updated in anticipation of the next
         * time the TG action is executed
         */
        lastGroupID = currentGroupID;
        }
        else
        /* If the number of terror groups has decreased or
         * remained the same, terrorGradient is set to the
         * basic value.
         */
        terrorGradient = basicTG;
       }
     }

   /*Beginning from step 0, record data as defined previously*/
   schedule.scheduleActionBeginning(0, new BasicAction() {
   public void execute() {
     recorder.record();
   }
 });

    /*Beginning from step 0, execute the TerrorPlexStep() method*/
     schedule.scheduleActionBeginning(0, new TerrorPlexStep());

     /*Write our recorded data to disk*/
     schedule.scheduleActionAtEnd(recorder, "writeToFile");

     /* Every 20 steps, the TerrorGradient is calculated. This is
      * done at the end of each step, starting on the 20th one.
      */
     schedule.scheduleActionAtInterval(20, new TerrorGradient(),
      Schedule.LAST);
}

/*Create an agent display and map to the display surface*/
public void buildDisplay(){
Object2DDisplay displayAgents =
new Object2DDisplay(tpSpace.getCurrentAgentSpace());
displayAgents.setObjectList(agentList);
dsurf.addDisplayable(displayAgents, "Agents");
}

/* Creates a TerrorPlexAgent object and its two biased media sources.
 * It is then added to the active agent list.
 */
public void addAgent() {
TerrorPlexAgent rascal = new TerrorPlexAgent(agentRespawn);
rascal.make_media_tags(biasProbability);
tpSpace.addAgent(rascal);
agentList.add(rascal);
}


/* When the respawn option is on, it is necessary to systematically
 * remove agents from simulation. So that this process is easily
 * managed, agents are removed when their lifetime expires.
 * If an agent's lifetime has reached zero, then the function
 * 'removeAgentAt()' that is provided in TerrorPlexSpace is called.
 * The agent is also removed from our active agent list, and if the
 * agent was an activist group member, that group's size is
 * decremented appropriately.
 */
private int reapDeadAgents(){
  int count = 0;
  for(int i = (agentList.size() - 1); i >= 0 ; i--){
    TerrorPlexAgent subject = (TerrorPlexAgent)agentList.get(i);
    if(subject.getLifetime() < 1){
     if(subject.getisActive()) {
    int group = subject.getmyGroup();
    subject.reduceGroupSize(group);
     }
      tpSpace.removeAgentAt(subject.getX(), subject.getY());
      agentList.remove(i);
```

```
      count++;
    }
  }
  return count;
}

/* Repast requires us to store and user-manipulated parameters in the
 * initParams string
 */
public String[] getInitParam(){
  String[] initParams = {
   "Population", "GridSize", "RestrictGroupSize",
   "MassMedia", "NeighbourMethod", "Range",
   "IgnoreOtherCultures", "Respawn", "StepLimit"
  };
  return initParams;
}

/* We always need the main() method to run the program, observing
 * standard Repast usage
 */
public static void main(String[] args) {
  SimInit init = new SimInit();
  TerrorPlexModel model = new TerrorPlexModel();
  init.loadModel(model, null, false);
}

/* Getters and Setters:
 * Required to facilitate elegant assignment of values to
 * variables, and their retrieval.
 */
public Schedule getSchedule(){ return schedule; }

public int getPopulation(){ return population; }
public void setPopulation(int popSize){ population = popSize; }

public int getGridSize() { return gridSize; }
public void setGridSize(int gridXY) { gridSize = gridXY; }

public int getRestrictGroupSize() { return Restrict; }
public void setRestrictGroupSize(int restrict) {
  Restrict = restrict;
  }

  public boolean getMassMedia() { return MassMedia; }
  public void setMassMedia(boolean massmedia) {
  MassMedia = massmedia;
  }

  public int getNeighbourMethod() { return NeighbourMethod; }
  public void setNeighbourMethod(int method) {
  NeighbourMethod = method;
  }

  public int getRange() { return Range; }
  public void setRange(int range) { Range = range; }

  public boolean getIgnoreOtherCultures() { return Ignore; }
  public void setIgnoreOtherCultures(boolean ignore) {
  Ignore = ignore;
  }

  public boolean getRespawn() { return Respawn; }
  public void setRespawn(boolean respawn) {Respawn = respawn; }

  public int getStepLimit() { return StepLimit; }
  public void setStepLimit(int limit) { StepLimit = limit; }

  public int getNumARM() { return numARM; }
  public int getNumALF() { return numALF; }
  public int getNumNeutral() { return numNeutral; }
  public int getNumAnti() { return numAnti; }
  public int getTagFlips() { return tagFlips; }
  public int getTerrorGroups() { return currentGroupID; }
  public double getTerrorGradient() { return terrorGradient; }

}
```

```
/*
 * Class: TerrorPlexAgent
 * TerrorPlexAgent provides the core functionality of the TerrorPlex
 * simulation. It is hoped that the coding style and commenting aid in
 * the reader's successful understanding of the program.
 */

package demo;

/*For defining colours to represent different agent types*/
import java.awt.Color;
/*For list construction*/
import java.util.Vector;
/*For enumerating through an agent's neighbours*/
import java.util.Enumeration;

import uchicago.src.sim.gui.Drawable;
import uchicago.src.sim.gui.SimGraphics;
import uchicago.src.sim.space.Object2DTorus;

public class TerrorPlexAgent implements Drawable {

/* The length of the (conceptually) binary string used to
 * represent the cultural make-up of each agent. The length is
 * intended to enable sufficient cultural diversity, without
 * incurring unacceptable computational overheads.
 */
private static final int tagLength = 9;

/* Thresholds used in converting an ALF agent to an activist,
 * and the recruiting of an agent by an existing activist
 * respectively. Arranged and used so that it is much easier for
 * an agent to be recruited by another than converted in isolation.
 */
private static final int recruitLimit = 3;
private static final int convertLimit = 4;

/* The required duration for two agents to be considered in a
 * strong trust relationship; being 'good friends'.
 */
private static final int timeForFriends = 50;

/* Upper and lower divisions of CIS for cultural groups.
 * upperDivision indicates the number of 1s in CIS for an agent to
 * be ALF. Below lower divison is Pro-Test.
 */
private static final int upperDivision = 6;
private static final int lowerDivision = 2;

/* Through trial and error, this rough value is used in the
 * isolation calculation
 */
private static final int isolationWeight = 1000;

/*Define colours we are going to use for each type of agent.
 * colorAnti (Pro-Test) is blue, colorNeutral is green
 * colorALF is red, and colorActive is white
 */
public Color colorAnti = new Color(0, 0, 255);
public Color colorNeutral = new Color(0, 255, 0);
public Color colorALF = new Color(255, 0, 0);
public Color colorActive = new Color(255, 255, 255);

/* These variables are used in the formation of ARM groups to
 * ensure that group size does not exceed the stipulated value.
 */
    private static int availableGroups = 10000;
    private static int latestGroupID;
    private static int[] groupList = new int[availableGroups];

    /*The space in which our agents exist*/
    private Object2DTorus tpSpace;
    /*An enumeration of an agent's neighbours' list*/
    public Enumeration neighbours;

    /* When incorporating the effect of mass media communications in
     * the model, two opposing cultures/opinions are used. The ALF
     * media communication consists mostly of 1's, whilst the anti-ALF
     * media string is mostly 0's.
     * Each agent has its own media sources, each with a (probable)
     * bias. However, very similar patterns have been observed when
     * only two central biased media sources are accessed by all
```

```
     * agents.
     */
    private int mediaALF[] = new int[tagLength];
    private int mediaAnti[] = new int[tagLength];

    /* Here follows a collection values for each agent object. */
private int x, y; // (x,y) coordinates within tpSpace
    private int law; // Respect for law and order (1-100)
    private int isolation; // Degree of isolation
    /* Pacifist disposition (1-100) with low values
     * denoting aggressiveness
     */
    private int pacifist;
    /*One's tendancy towards activism, deduced from other values*/
    private double tendancy;
    /*If belonging to an ARM group, group number is stored here*/
    private int myGroup;
    private int lifetime; // Lifetime!
    /*How long has been in position - indicates trust*/
    private int myDuration;
    /*Individual cultural identity string*/
    private int[] CIS = new int[tagLength];

    /* A collection of possible affiliations */
private boolean isAnti; //Agent opposes ALF
    private boolean isALF; //Agent is ALF
    /*Agent is an activist (ARM) -> implies also ALF*/
    private boolean isActive;

    /* The boolean variable 'flipped' is used in the reporting
     * mechanism to establish whether a cultural exchange has taken
     * place recently (in the last step).
     */
    private boolean flipped;

    /* Responsible for setting the intitial attribures of each agent,
     * the TerrorPlexAgent() method takes just one argument which is
     * the boolean respawn parameter set from the user interface.
     */
public TerrorPlexAgent(boolean agentRespawn) {
/* If respawning is not allowed, then each agent, upon
 * simulation setup can be assigned the same value
 * for 'latestGroupID'. This is not so when respawn is on,
 * since new agents introduced to the simulation are possibly
 * following the existence of activist groups.
 */
if(agentRespawn == false)
latestGroupID = 0;

/*Randomly assign culture tags to current agent*/
for(int tag = 0; tag < tagLength; tag++) {
int tagVal = (int)Math.round((Math.random()));
this.setTag(tag, tagVal);
}

/*How law-abiding is this agent? On a scale of 0 to 100 please*/
int tempLaw = (int)(Math.random() * 100);
this.setLaw(tempLaw);

/*How much of a pacifist is the agent? Again, range is 0 to 100*/
int tempPacifist = (int)(Math.random() * 100);
this.setPacifist(tempPacifist);

/* Set a lifetime. This is only actually used if 'respawn' is
 * on. However, it seems more elegant to create and store this
 * small integer rather than pass another argument to
 * TerrorPlexAgent().
 */
int tempLife = (int)(Math.random() * 200);
this.setLifetime(tempLife);

/* Duration is a synthetic measurement of how long an agent
 * has resided in their grid location. It is used when
 * determining the strength of friendships between agents,
 * and as set randomly over a large range of 50 to introduce
 * variance to the simulation.
 */
int tempDuration = (int)(Math.random() * 50);
this.setDuration(tempDuration);

/* Finally, the switch_culture() method is called to set the
 * agent's cultural identity.
```

```
 */
switch_culture();
}

/* At each step or 'tick' in the simulation, this method is
 * executed for every agent, and so in a sense, provides the core
 * functionality of the simulation.  It accepts as arguments
 * several parameters which are manipulated through the user
 * interface.
 */
public void step(int NeighbourMethod, int Range, int Restrict,
boolean MassMedia, boolean Ignore, double terrorGradient,
int population) {

/* A list of an agent's current neighbours are stored as a
 * vector type
 */
Vector neighbourList;

/* Repast provides the rather useful 'getVonNeumanNeighbours'
 * and 'getMooreNeighbours' methods to obtain a list of
 * neighbours using the von Neuman or Moore techique
 * respectively. These accept a physical 'range' in which
 * neighbours shall be sought.
 */
if(NeighbourMethod == 1)
neighbourList = tpSpace.getVonNeumannNeighbors(
this.x, this.y, Range, Range, false);
else
neighbourList = tpSpace.getMooreNeighbors(
this.x, this.y, Range, Range, false);

/* The relative isolation of an agent is calculated as a
 * function of the isolation weighting divided by number of
 * the agent's neighbours (plus one to avoid division by zero).
 */
this.setIsolation(isolationWeight / (neighbourList.size() + 1));

/* If the mass media argument is 'true', then the terrorGradient
 * is factored in when calculating an agent's propensity for
 * violent action, or 'tendancy' here. If mass media is passed
 * as 'false', then the value of 0.1 is factored in, where
 * 0.1 is the default terrorGradient as defined in
 * TerrorPlexModel  by the variable 'basicTG'. This basicTG
 * value should probably be passed to this method to ensure
 * consistency, but the overhead of passing yet another value
 * put me off.
 */
if(MassMedia == true)
this.setTendancy(this.getIsolation() /
(this.getLaw() + this.getPacifist() + terrorGradient));
else
this.setTendancy(this.getIsolation() /
(this.getLaw() + this.getPacifist() + 0.1));


neighbours = neighbourList.elements();
this.setFlip(false);

/* Select a different method depending upon the agent's
 * cultural type
 */
if(this.getisActive() == true)
process_as_activist(Restrict, population);
else if(this.getisALF() == true)
process_as_ALF();
else if(this.getisAnti() == true)
/*Anti-ALF (Pro-Test) agents do nothing*/
;
else
process_as_neutral(Ignore, MassMedia, terrorGradient);

/* The lifetime of an agent should be decremented upon each
 * step. In a _very_ long-running simulation (without respawn),
 * underflow could potentially occur, so the lifetime is only
 * decremented if more than zero.
 */
if(lifetime > 0) lifetime--;

/*Increase duration after each step*/
myDuration++;
}
```

```
public void setTerrorPlexSpace(Object2DTorus tps){
tpSpace = tps;
}

/*getCulture() returns the number of 1s in an agents CIS*/
public int getCulture() {
int sum = 0;
for(int i = 0; i < tagLength; i++)
sum = sum + this.CIS[i];
return sum;
}

/* If identified as an activist, then our agent attempts to
 * recruit new members into its group from surrounding neighbours.
 */
public void process_as_activist(int Restrict, int population) {
/*Iterate through neighbour list*/
while(neighbours.hasMoreElements() == true) {
TerrorPlexAgent temp =
(TerrorPlexAgent)neighbours.nextElement();
/* If a neighbouring agent is culturally ALF, not an
 * activist already, has a tendancy below the recruitLimit
 * threshold, and has been a neighbour long enough to be a
 * 'friend' then recruitment is attempted.
 */
if(temp.getisALF() && (!temp.getisActive() &&
(temp.getTendancy() < recruitLimit)) &&
(calculate_trust(temp) > timeForFriends)) {
if(Restrict != 0)
/* Attempt to recruit member in accordance with
 * size restrictions
 */
recruitMember(temp, this.getmyGroup(), Restrict);
else
/* The population is passed as an argument to
 * recruitMember() is no group size restrictions
 * are active, to ensure that the agent will always
 * be recruited. This is because the group size can
 * never exceed the total population.
 */
recruitMember(temp, this.getmyGroup(), population);
}
}
}

/*Processed when an agent is identified as ALF*/
public void process_as_ALF() {
/* If the agent's tendancy value exceeds the threshold set in
 * convertLimit, then it becomes an activist agent, and begins
 * a new group.
 */
if(this.getTendancy() > convertLimit) {
this.setisActive(true);
this.setmyGroup(latestGroupID);
/* Ensure we avoid an array out of bounds exception by
 * using the if conditional
 */
if(latestGroupID < 0) latestGroupID = 0;
groupList[latestGroupID] = 1;
/* Increment so that we move 'forward' in the groupList
 * array next time
 */
latestGroupID++;
}
}

/* If the agent has been identified as culturally neutral, then
 * either flip_tags_fair() or flip_tags_biased() is slected
 * depending upon whether the 'Ignore' option is set, indicating
 * that other cultures should be 'ignored', or left out of
 * cultural exchanges.
 */
public void process_as_neutral(boolean Ignore,
boolean MassMedia, double terrorGradient) {
if(Ignore == true)
flip_tags_biased(MassMedia, terrorGradient);
else
flip_tags_fair(MassMedia, terrorGradient);

/* Following exchanges, the agent's CIS may have altered
 * sufficiently for it to be classified as belonging to another
```

```
 * culture, so we check and change is required.
 */
switch_culture();
}

/* The mass_media_influence() method is an attempt to incorporate
 * the influence of popular media sources into an agent's cultural
 * identity. This model does not currently consider Pro-Test or ALF
 * agents as being influenced by the media, as it is unclear whether
 * the effect on these groups would be moderating or reinforcing.
 * However, provision is made within the method for such an
 * expansion.
 */
public int mass_media_influence(int thisTagNo, int thisTagVal) {
int tempCulture  = this.getCulture();
int mediaTagVal;
int enforced = 0;

/* If an ALF agent, a tag comparison is made but only from the
 * agent's source which is biased towards the ALF ideal CIS of
 * mostly 1s.
 */
if(tempCulture > upperDivision ) {
mediaTagVal = mediaALF[thisTagNo];
if(thisTagVal == mediaTagVal)
enforced = 1;
else
enforced = -1;
}

/* This is the usual case, used by neutral agents. The tag
 * position is compared with one of the agent's two biased
 * media sources, selected at random.
 */
else if(tempCulture > lowerDivision) {
int source = (int)Math.round(Math.random());

/* Meeting this conditional results in comparison with the
 * ALF media source
 */
if(source == 0) {
mediaTagVal = mediaALF[thisTagNo];
if(thisTagVal == mediaTagVal)
enforced = 1;
else
enforced = -1;
}
/* Meeting this conditional results in the comparison with
 * the Pro-Test source
 */
else {
mediaTagVal = mediaAnti[thisTagNo];
if(thisTagVal == mediaTagVal)
/* If tags match, then enforce location. Termed
 * elsewhere as a 'hit'
 */
enforced = 1;
else
/* If tags differ, reduce force of location. Termed
 * elsewhere as a 'miss'
 */
enforced = -1;
}
}
/* If agent is not ALF or neutral, then it is Pro-Test.
 * Operation here is similar to that of the ALF option, except
 * that the Pro-Test media source is used.
 */
else {
mediaTagVal = mediaAnti[thisTagNo];
if(thisTagVal == mediaTagVal)
enforced = 1;
else
enforced = -1;
}
return enforced;
}

/* This method returns the smallest duration between two
 * (neighbouring agents)
 */
public int calculate_trust(TerrorPlexAgent temp) {
```

```
if(temp.getDuration() > this.getDuration())
return this.getDuration();
else
return temp.getDuration();
}

/* The first of two similar methods (the second being
 * flip_tags_biased(), this one provides a mechanism whereby an
 * agent may adjust an element of its Cultural Identity String if
 * the majority of its neighbours have a different value at the
 * same position.
 * This is a function only performed by neutral agents, and in this
 * 'fair' routine, Pro-Test, ALF and other neutral agents are all
 * included. The only agents to be excluded are activists.
 */
public void flip_tags_fair(boolean MassMedia, double terrorGradient){
int hits = 0;
int misses = 0;
int alternative = 0;
int tempTag = 0;
/*Randomly select a tag position*/
int t = (int)(Math.random() * tagLength);
int thisTag = this.getTag(t);
/*Iterate through neighbour list*/
while(neighbours.hasMoreElements() == true) {
/*Make temporary agent 'temp'*/
TerrorPlexAgent temp =
(TerrorPlexAgent)neighbours.nextElement();
/*Skip neighbour agent if an activist*/
if(temp.getisActive() != true) {
tempTag = temp.getTag(t);
/* Compare value at tag position of this
 * and temp agent.
 */
if(tempTag != thisTag) {
misses++;
alternative = tempTag;
}
else
hits++;
}
}

/* Include mass media influence if parameter has been set
 * to true.
 */
if(MassMedia == true) {
/*If randomly generated number less than terrorGradient,
 * then incorporate a media influence. This is so that
 * media is not _always_ a factor, except when the terror
 * gradient exceeds 1 of course (since 0 >= random() <= 1).
 */
if(Math.random() < terrorGradient) {
hits =+ mass_media_influence(t, thisTag);
}
}

/* If most neighbours have a different value for the same tag
 * position (i.e. more misses than hits) then the agent sets
 * their tag to the value of the majority.
 */
if(hits<misses) {
/*Swap this agent's tag. 0 -> 1, 1 -> 0*/
this.setTag(t, alternative);
this.setFlip(true);
}

}

/* Where flip_tags_fair() acknowleges the existence of Pro-Test,
 * ALF and neutral agents, this method excludes any culturally
 * different agents. Since this method is only called by neutral
 * agents, only those are included.
 */
public void flip_tags_biased(boolean MassMedia,
double terrorGradient) {
int hits = 0;
int misses = 0;
int alternative = 0;
int tempTag = 0;
boolean sameCulture = true;
/*Randomly select a tag position*/
```

```
int t = (int)(Math.random() * tagLength);
int thisTag = this.getTag(t);
/*Iterate through neighbour list*/
while(neighbours.hasMoreElements() == true) {
/*Create temporary agent 'temp'*/
TerrorPlexAgent temp =
(TerrorPlexAgent)neighbours.nextElement();
/* If this agent and temp agent differ in culture,
 * sameCulture flag set false.
 */
if(temp.getisALF() == true)
sameCulture = false;
if(temp.getisAnti() == true)
sameCulture = false;

/*If of same culture, tag comparisons can be made*/
if(sameCulture == true) {
tempTag = temp.getTag(t);
/*Compare value at chosen tag position*/
if(tempTag != thisTag) {
misses++;
/*Swap this agent's tag. 0 -> 1, 1 -> 0*/
alternative = tempTag;
}
else
hits++;
}
}

/* If mass media is being used, then a media influence is
 * factored in, mimicing a normal, physical neighbour.
 */
if(MassMedia == true) {
if(Math.random() < terrorGradient) {
hits =+ mass_media_influence(t, thisTag);
}
}

/* If most neighbours have a different value for the same tag
 * position (i.e. more misses than hits) then the agent sets
 * their tag to the value of the majority.
 */
if(hits < misses) {
this.setTag(t, alternative);
this.setFlip(true);
}

}
/* This method counts the uses getCulture() to return the number
 * of 1s in the agent's CIS. The agent's isALF and isAnti flags
 * are set accordingly depending upon which threshold is met.
 */
public void switch_culture(){
if(this.getCulture() > upperDivision) {
this.setisALF(true);
this.setisAnti(false);
}
else if(this.getCulture() > lowerDivision) {
this.setisALF(false);
this.setisAnti(false);
}
else {
this.setisALF(false);
this.setisAnti(true);
}
}

/* Only used when it has been confirmed that an agent meets any
 * requirements governing whether it may be recruited as an
 * activist, recriutMember() adds the given agent to a group. The
 * group is the group of the agent's recruiter. This opperation is
 * only possible if the group size is currently less than its
 * maximum size, given by 'restrict'. If successful, the group size
 * is incremented, and the agent's  'myGroup' attribute is
 * set accordingly.
 */
public void recruitMember(TerrorPlexAgent temp,
int thisGID, int Restrict) {

int currentMembers = groupList[thisGID];
if(currentMembers < Restrict) {
temp.setmyGroup(thisGID);
```

```
groupList[thisGID] = groupList[thisGID] + 1;
temp.setisActive(true);
}
}

/* Accessed when an activist agent is removed from the agent
 * space, this method decrements by one, the size of the ARM
 * group to which the agent belonged.
 */
public void reduceGroupSize(int group) {
groupList[group] = groupList[group] - 1;
if(groupList[group] == 0)
latestGroupID--;
}

/* All of the computations culminate in this very simple method in
 * which each agent is drawn as a circle (in representative colour)
 * on to our two dimensional grid.
 */
public void draw(SimGraphics G){
if(this.getisActive() == true)
G.drawFastCircle(colorActive);
else if(this.getisALF() == true)
G.drawFastCircle(colorALF);
else if(this.getisAnti() == true)
G.drawFastCircle(colorAnti);
else
G.drawFastCircle(colorNeutral);
}

/* Each agent has two CIS strings which represent two biased media
 * sources. Weighted probabilites are used to encourage the
 * mediaALF CIS to consist mostly of 1s, and the mediaAnti CIS to
 * be mostly 0s. The method iterates through each binary array in
 * turn, assigning 1 or 0 to every element.
 */
public void make_media_tags(double probability) {
for(int tag = 0; tag < tagLength; tag++) {
if((double)Math.random() < probability)
mediaALF[tag] = 1;
else
mediaALF[tag] = 0;
}
for(int tag = 0; tag < tagLength; tag++) {
if((double)Math.random() > probability)
mediaAnti[tag] = 1;
else
mediaAnti[tag] = 0;
}
}

/* Getters and Setters:
 * A number of these are necessary for the elegant use of object
 * variables. It may be that one or more of these methods are
 * currently unused, but good practice dictates that get/set pairs
 * be included where possible.
 */
public void setXY(int newX, int newY){ x = newX; y = newY; }

public int getX(){ return x; }
public int getY(){ return y; }

public int getTag(int tag) { return CIS[tag]; }
public void setTag(int tag, int tagValue) {
this.CIS[tag] = tagValue;
}

public int getIsolation() { return isolation; }
public void setIsolation(int isolation) {
this.isolation = isolation;
}

public double getTendancy() { return tendancy; }
public void setTendancy(double tendancy) {
this.tendancy = tendancy;
}

public int getLaw() { return law; }
public void setLaw(int law) { this.law = law; }

public int getPacifist() { return pacifist; }
public void setPacifist(int pacifist) { this.pacifist = pacifist; }
```

```
public int getLifetime() { return lifetime; }
public void setLifetime(int TTL) { this.lifetime = TTL; }

public int getDuration() { return myDuration; }
public void setDuration(int duration) { myDuration = duration; }

public boolean getisActive() { return isActive;}
public void setisActive(boolean state) { isActive = state; }

public boolean getisALF() { return isALF; }
public void setisALF(boolean state) { isALF = state; }

public boolean getisAnti() { return isAnti; }
public void setisAnti(boolean state) { isAnti = state; }

public int getmyGroup() { return myGroup; }
public void setmyGroup(int groupID) { myGroup = groupID; }

public boolean getFlip() { return flipped; }
public void setFlip(boolean state) {flipped = state; }

public int getLatestGroupID() { return latestGroupID; }
public void resetGroupCount() { latestGroupID = 0; }
}
```

```
/*
 * Class: TerrorPlexSpace
 * Responsible for the creation and maintenance of the agent space.
 * The space, although projected as a grid is actually a torus object.
 * This was chosen to maximise integration of agents in the environment.
 */

package demo;

import uchicago.src.sim.space.Object2DTorus;

public class TerrorPlexSpace {

/* As mentioned, our space is of the type Object2DTorus */
private Object2DTorus mySpace;

/* Instantiate our space object with chosen dimensions*/
public TerrorPlexSpace(int x, int y) {
mySpace = new Object2DTorus(x, y);
}

/* Used from within TerrorPlexModel when displaying the agent
 * space.
 */
public Object2DTorus getCurrentAgentSpace() {
return mySpace;
}

/* This method is given an x-y pair which define the coordinates
 * of a location in our agent space. If that location is occupied
 * by an agent, then a boolean 'true' is returned, and the default
 * of 'false' is returned otherwise.
 */
public boolean isCellOccupied(int x, int y){
    boolean retVal = false;
    if(mySpace.getObjectAt(x, y)!= null) retVal = true;
    return retVal;
}

/* The addAgent() method accepts an agent object, which is
 * attempts to insert into the agent space at an unoccupied
 * location. x-y pairs are randomly generated, but attempts
 * to find a free space are limited to 10 times the area of
 * the agent space, which is simply chosen as a suitably large
 * number. In earlier work, this was handled by the
 * getNextIntFromTo() method to drawn a value from a free list.
 * However, seemed not to be usuable after the move from
 * SimpleModel to SimModelImpl, and so this more hit and miss
 * approach has been adopted.
 */
public boolean addAgent(TerrorPlexAgent rascal){
    boolean retVal = false;
    int count = 0;
    int countLimit = 10 * mySpace.getSizeX() * mySpace.getSizeY();

    while((retVal==false) && (count < countLimit)){
      int x = (int)(Math.random()*(mySpace.getSizeX()));
      int y = (int)(Math.random()*(mySpace.getSizeY()));
      if(isCellOccupied(x,y) == false){
     /* Having found an available location, the agent object
      * is inserted into the agent space with the built-in
      * method 'putObjectAt(x coord, y coord, object)'
      */
     mySpace.putObjectAt(x,y,rascal);
        rascal.setXY(x,y);
        rascal.setTerrorPlexSpace(mySpace);
        retVal = true;
      }
      count++;
    }
    /* If a free space has not been found, the flag 'retVal' is
     * returned with its default value of false. Success
     * returns true.
     */
    return retVal;
}
/* Agents are not exactly 'removed' from the agent space, but
 * rather over-written with a null object.
 */
public void removeAgentAt(int x, int y){
mySpace.putObjectAt(x, y, null);
}
}
```

Appendix C

Repast and the Research Student

One of the earliest stipulations governing ones approach to social simulation; to this 'generative social science', was that models should be as simple as possible. Whilst we (usually) wish to devise a simulation that resembles the real world, we cannot, and should not, expect to capture the infinite complexities of a genuine social observance. It is apt then, that Repast provides a framework so simple as to enable the researcher to begin their experiments in a remarkably short time.

There is so much functionality already encapsulated in the building blocks of a Repast simulation, that one is likely to find themselves terribly under whelmed when performing a cursory check of the line count. It is often the case that a programmer begins to interpret the importance of their work as being somehow proportional to code length. Repast seems to make the point that this is not a sensible yard–stick by which to work, and the person using Repast for the first time will likely gaze astounded as Conway's Game of Life plays itself out on screen with what amounts to barely more than a handful of code. Of course, there is an awful lot going on behind the scenes, but the user is shielded from this complexity and allowed to focus their attention upon the behaviour, attributes and rule sets that are so dear to their hearts.

It is possible to follow almost blindly the template specification for a basic simulation—that is, one that extends the SimpleModel base class. It is not much more effort to translate basic textually–defined rules into methods so that the developmental process is given a very encouraging kick-start. That said, one must be stress that it would be inappropriate to suggest that anyone—even competent programmers—should take a collection of loosely–defined behavioural semantics and expect Repast to magically transform these into useful code. The sensible scientist[1] will have already deduced succinct, unambiguous, and implementable rules and behaviours through the normal processes inherent to the development of any system; perhaps most usefully an iterative process of modelling and refinement stemming

[1]As we are studying social science, it is reasonable to refer to ourselves in this case as scientists.

from a carefully elicited set of requirements.

It may be the case that those involved primarily with computer studies find difficulty in extracting the salient programmable features of a given social system, and it may also be the case that those involved primarily with the social sciences have difficulty in expressing abstract sociological concepts in, say, Java or Python. Regrettably, it would seem that for the former, there are few short–cuts. For the latter however, there exist an increasing number of useful tools. Repast is but one of them, being of sufficient simplicity to empower even the novice programmer to progress quickly.

Although it would probably be incorrect to claim that I myself am a novice programmer, proficiency in—and certainly fondness of—Java is very limited. However, the marriage of Repast and Eclipse, together with the support of such sources as Murphy (2005) and Gieseler (2004) have made the production of a sound model a reasonably painless exercise. The increased use of agent–based modelling by interested persons from *any* academic background is highly recommended, and interested persons are directed to the good introductory paper from Axelrod (2003).